

CUE 02 0003



Auburn University

Auburn University, Alabama 36849-5418

School of Forestry

Southern Forest Nursery Management
Cooperative
Office of the Director

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September 4, 2002

To: U.S. Environmental Protection Agency
Methyl Bromide Critical Use Exemption
Global Programs Division, Mail Code 6205J
1200 Pennsylvania Ave, NW
Washington, DC 20460-0001

From: Ken Mc Nabb, Director
Auburn University Southern Forest Nursery Management Cooperative
School of Forestry and Wildlife Sciences
Auburn University, AL 36849-5418

**Subject: APPLICATION FOR A CRITICAL USE EXEMPTION
OF METHYL BROMIDE**

Enclosed is an application for a Critical Use Exemption of methyl bromide. This application is being forwarded by the Auburn University Southern Forest Nursery Management Cooperative (the "Consortium") on behalf of forest tree nurseries in the southeastern United States. The consortium is comprised of 11 state government forestry organizations, 8 major forest products companies, the U.S. Forest Service, and 2 private non-industrial nurseries. The consortium is making this application on behalf of all forest tree seedling nurseries producing bareroot planting stock in 12 southeastern states. These nurseries collectively grow approximately 80% of all the forest tree seedlings in the United States. These seedlings are used to replant or otherwise establish forests on about 1.5 million acres for the purposes of fiber production, ecosystem restoration, wildlife habitat, soil conservation, and aesthetics. Methyl bromide is used as a soil fumigant to protect seedlings from soil and weed pests. The use of methyl bromide results in larger and healthier seedlings that have higher outplanting survival and growth rates, which has tremendous impact on the economic and environmental health of the entire forestry sector in the southeastern United States. The consortium believes and this application demonstrates, that the loss of methyl bromide will result in a "significant market disruption" not only to the forest tree nursery business, but also through large-scale negative effects on forest industry and environmental programs supporting ecosystem restoration and soil conservation.

Worksheet 1. Contact and Methyl Bromide Request Information

The following information will be used to determine the amount of methyl bromide requested and the contact person for this request. It is important that we know whom to contact in case we need additional information during the review of the application.

1. Location

(Enter the state, region, or county. Provide more detail about the location if relevant to the feasibility of alternatives to methyl bromide.)

The southeastern United States, specifically the states of

Alabama	Louisiana	South Carolina
Arkansas	Mississippi	Tennessee
Georgia	North Carolina	Texas
Florida	Oklahoma	Virginia

2. Crop/commodity

(Include all crops/commodities that benefit from the application of methyl bromide in a fumigation cycle. A fumigation cycle is the period of time between methyl bromide fumigations.)

Nursery grown bare root tree seedlings used for reforestation: conifers such as *Pinus taeda*, *P. elliotii*, and *P. palustris*, *Abies fraseri*, *Taxodium distichum* (96% of production) and various deciduous (hardwood) species. *P. taeda* (loblolly pine) and *P. elliotii* (slash pine) are the primary fiber sources for the forest industry in the southeastern United States and nursery stock is used to establish plantations that upon maturity in 20 to 30 years provide the raw material to forest industry. *Pinus palustris* (longleaf pine), is also an important timber species and widely planted for that purpose. Recently, however, it has become the focus of ecosystem restoration efforts supported by the federal government. Nurseries produce between 30 to 40 species of hardwood planting stock in the southeastern U.S. Principle among these are the genus *Quercus*, *Carya*, *Liquidambar*, *Populus*, *Platanus*, and *Fraxinus*. While hardwood planting stock may serve to establish fiber plantations, they are most commonly planted for wildlife, aesthetic, and ecosystem restoration objectives.

3. Climate

(Individual users should enter their climate zone designation by reviewing the U.S. climate zone map. If a consortium is submitting this application, please indicate the estimated percentage of consortium users in each climate zone. This map is located at the end of this workbook or it can be reviewed online at <http://www.usna.usda.gov/Hardzone/ushzmap.html>).

The southeastern United States covers three climate zones and consortium nurseries are located in all three.

zone 6	approximately 10% of production
zone 7	approximately 25% of production
zone 8	approximately 65% of production

- 4. Soil type** Check the box(es) for the soil types and percent organic matter that apply to your area. If a consortium is submitting this application, please indicate the estimated percentage of consortium users in each soil type.

Soil Type:	Light	X	Medium	Heavy	
Organic Matter:	0 to 2%	80	2 to 5 %	20	over 5% _____

Almost all members

- 5. Other geographic factors that may affect crop/commodity yield (e.g., water table).**

None

6. Consortium name	Auburn University Southern Forest Nursery Management Cooperative	Specialty (check one)
7. Contact name	Ken McNabb	agronomic <input checked="" type="checkbox"/> _____
8. Address	108 M. White Smith Hall Auburn University, AL 36849	economic _____
9. Daytime phone	334-844-1044	10. FAX 334-844-4873
11. E-mail	mcnabk1@auburn.edu	

Worksheet 1. Contact and Methyl Bromide Request Information

For EPA Use Only
ID# _____

List an additional contact person if available.

Specialty (check one)

12. Contact name William Carey

agronomic ☒ _____

13. Address 108 M. White Smith Hall

economic _____

Auburn University, AL 36849

14. Daytime phone 334-844-4998

15. FAX 334-844-4873

16. E-mail careywa@forestry.auburn.edu

17. How much active ingredient (ai) of methyl bromide are you requesting for 2005? 542,408 lbs.

If a consortium is submitting this application, the data for question 17 and 17a. should be the total for the consortium.

In the question below, area is defined as follows for each user: acres for growers, cubic feet for post harvest operations, and square feet for structural applications.

17a. How much area will this be applied to? Please list units. 1,621 Acres units

18. Are you requesting methyl bromide for additional years beyond 2005? Yes ☒ No _____

18a. If yes, please list year and quantity active ingredient (ai) of methyl bromide requested in the table below and explain why you need authorization for multiple years.

Requests beyond 2005

Specific sections of seedling production areas are fumigated each year. The request for a Critical Use Exemption is based on this annual application requirement.

2006 542,408

2007 542,408

If a consortium is submitting this application, the data below should be the total for the consortium.

In the table below, area is defined as follows for each user: acres for growers, cubic feet for post harvest operations, and square feet for structural applications.

Year	Quantity ai (lb.) of Methyl Bromide	Area to be Treated	Unit of Area Treated
2006	542,408	1621	Acres
2007	542,408	1621	Acres

19. Target Pest(s) or Pest Problem(s):

(Be as specific as possible about the species or classes of pests relevant to the feasibility of alternatives.)

Fumigation targets a broad spectrum of fungal pathogens, nematodes, and weeds. Specific examples include the fungus *Macrophomina* (a root rot) which has historically caused crops to be condemned in some nurseries, *Cylindrocladium* spp., *Fusarium solani*, *Pythium irregulare*, and *Rhizoctonia solani*. Fumigation has been shown to be critical for the control of nematodes such as *Criconeoides* spp. *Helicotylenchus* spp, and others which have caused significant crop loss in some locations. Moreover, fumigation is the foundation of the weed control programs dealing with certain herbaceous weeds of the genus *Cyperus*, for which there is no currently labeled effective nursery product. Deciduous hardwoods are particularly susceptible to *Phytophthora*, *Fusarium*, and *Pythium* root rots in the damping-off phase and throughout the spring and summer months. The cost effective treatment of such a broad range of pests with a single compound is what makes methyl bromide an essential compound.

Worksheet 1. Contact and Methyl Bromide Request Information

20. If applying as a consortium for many users of methyl bromide, please define a *representative user*. Define exactly, issues such as size of the operation (acres treated with methyl bromide for growers, cubic feet for post-harvest operations, and square feet for structural applications), whether the representative user owns or rents the land or operation, intensity of methyl bromide use (treat regularly or only when pest reaches a threshold), pest pressure, etc.

Representative User

Forest tree nurseries in the southeastern United States typically produce 20 to 30 million bareroot seedlings per year. Pine seedlings are approximately 96% of this production, with the balance made of deciduous hardwood species. The general category of "pines" includes *P. taeda*, *P. elliotii*, and a variety of other similarly cultured seedling crops (78%, 20%, and 2% of pine production, respectively). A second category of "pine" is "Longleaf" (*Pinus palustris*) which has a distinct nursery culture requiring wide bed spacing and comparatively more nursery area. Pine seedling crops are typically grown on 2:2 rotations with 2 years of seedlings followed by 2 years of cover crops. Fumigation occurs once in this 4 year cycle and immediately prior to the first seedling crop. One fumigation will last 2 seedling crops (2 years).

The third category of seedling is deciduous hardwoods. Hardwood seedling culture requires fumigation prior to each seedling crop. Both weed and disease control are more critical for hardwood culture. There is a general lack of selective weed control chemicals for hardwood seedling culture and hardwoods are more susceptible to damping off and root rot fungi.

Nurseries are owned by forest industry, state governmental forestry organizations, and private non-industrial nurseries, (70%, 20% and 10% of regional production, respectively). Consortium nurseries are distributed throughout the region.

20a. Explain why this user represents the typical user in the consortium.

This characterization of a "typical user" is based on surveys and direct interaction with nursery managers/owners. Our consortium has been instrumental in the development of a southern forest tree nursery research and technology transfer program for over 20 years. We are very familiar with the characteristics of a typical user and their activities. Moreover, this knowledge base has been supplemented in recent years through formal written surveys.

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7. Contact name	<u>Ken McNabb</u>	agronomic <u>X</u>
8. Address	<u>108 M. White Smith Hall</u> <u>Auburn University, AL 36849</u>	economic _____
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List an additional contact person if available.

Specialty (check one)

12. Contact name William Careyagronomic ☒ _____13. Address 108 M. White Smith Hall

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Auburn University, AL 3684914. Daytime phone 334-844-499815. FAX 334-844-487316. E-mail careywa@forestry.auburn.edu17. How much active ingredient (ai) of methyl bromide are you requesting for 2005? 542,408 lbs.

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Worksheet 2. Methyl Bromide - Historical Use of Methyl Bromide

Purpose of Data: To establish a baseline estimate of crop/commodity yields, gross revenues, and costs using methyl bromide.		
Worksheet	Title	Instructions specific to each worksheet are located at the top of each sheet.
2-A	Methyl Bromide Use for 1997 - 2000	This worksheet provides data in actual usage for 1997-2000.
2-B	Methyl Bromide - Crop/Commodity Yield and Gross Revenue for 1997-2000	This worksheet provides crop/commodity yield and gross revenue for 1997 through 2000.
2-C	Methyl Bromide - Crop/Commodity Yield and Gross Revenue for 2001	This data provides historical information on crop/commodity yield and gross revenue for 2001.
2-D	Methyl Bromide Use and Costs for 2001	This worksheet isolates use and cost data for 2001.
2-E	Methyl Bromide - Other Operating Costs for 2001	This data is needed to estimate a baseline for operating costs in order to estimate the impact on operating profit and short-run economic viability as a result of not using methyl bromide.
2-F	Methyl Bromide - Fixed And Overhead Costs for 2001	This data is needed to estimate a baseline for total costs in order to estimate the impact on profitability and long-run economic viability as a result of not using methyl bromide.

Worksheet 2-B. Methyl Bromide - Crop/Commodity Yield and Gross Revenue 1997-2000

If a consortium is submitting this application, the data for this table should reflect the actual averages for the consortium.

The purpose of this worksheet is to estimate the gross revenue for 1997 - 2000 when using methyl bromide. Post-harvest and structural users may work with EPA to modify this form to accommodate differences in operations when providing gross revenue data.

Col. A: Year 2000	Be sure to enter the year. Use as many rows as needed for each year for all the crops/commodities in the fumigation cycles from 1997 to 2000. If a fumigation cycle overlaps more than one calendar year, then the year of the fumigation cycle is the year methyl bromide was applied.
Col. B: Crop/Commodity Forest Tree Seedlings Pine & Hardwoods	Enter all crops/commodities that benefit from methyl bromide in each fumigation cycle. (For example, if normally methyl bromide is applied and tomatoes are grown and harvested followed by peppers without an additional treatment of methyl bromide, then both tomatoes and peppers would be part of the same fumigation cycle.) See the Fumigation Cycle Worksheet for a comprehensive definition of the fumigation cycle. If someone other than the applicant benefits from the application of methyl bromide in the fumigation cycle and you do not have the quantitative data for the crops grown on the same land, please indicate so in the comments section below.
Col. C: Unit of Crop/Commodity	Enter the unit of measurement for each crop/commodity.
Col. D: Crop/Commodity Yield	Enter the number of units of crop/commodities produced per area.
Col. E: Price	Enter the average prices received by the users for the year and crop/commodity indicated (1997-2000).
Col. F: Revenue	This number is calculated automatically using the values you entered in Cols. D and E. You may override the formula to enter a different revenue. Please explain why the revenue amount is different in the comment section below.
Total Revenue for 1997-2000	Enter the total revenue per year by adding the revenue for all crops for that year.
Average Revenue per Year:	The average revenue per year is calculated automatically using the summary data you enter for each year.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F
Year Methyl Bromide was Applied	Crop/Commodity	Unit of Crop/Commodity (e.g., pounds, bushels)	Crop/Commodity Yield (Units per area)	Price (per unit of crop/commodity)	Revenue (per area)
2000	Pine Spp	1000 trees	631	\$ 40.00	\$25,240/ac
	Longleaf	1000 trees	343	\$ 60.00	20,580/ac
	Hardwoods	1000 trees	197	\$ 250.00	49,250/ac
				Total Revenue for 1997	
				Total Revenue for 1998	
				Total Revenue for 1999	
				Total Revenue for 2000	\$81.1 million/Consortium
				Average Revenue Per Year	\$81.1 million/Consortium

Comments: Crop/Commodity Yield and Gross Revenue 1997-2000

The basic mandate of our consortium has been research and technology transfer. As such we have not historically kept records of seedling sales. We have data for the year 2000 which was obtained by surveying consortium members. We see no reason, however, that the annual revenue from seedling sales will vary a great deal (other than a slight increase due to inflation) and it can be assumed that gross revenues in 1997 to 1999 will be similar to that of the year 2000.

Table 2b. Calculation of region-wide nursery revenue for the year 2000*

Crop	Acres	Value/acre	Revenue
Pines	2646	\$25,240	\$66.8 Million
Longleaf	87	\$20,580	\$1.8
Hardwoods	254	\$49,250	\$12.5
TOTAL REVENUE			\$81.1 Million

* Includes all nursery acres, not just the 50% fumigated annually since all seedling production acres are fumigated at least once although it may have been done the previous year.

Worksheet 2-C. Methyl Bromide - Crop/Commodity Yield and Gross Revenue 2001

If a consortium is submitting this application, the data for this table should reflect the **representative user** for the consortium.

The purpose of this worksheet is to estimate the gross revenue for 2001 when using methyl bromide. Post-harvest users may modify this form to accommodate differences when providing gross revenue data. If 2001 was not a typical year for the individual or for the representative user of a consortium, the applicant may provide additional data for a different year. However, all applicants must complete this worksheet for the year 2001 regardless. Please explain in the comment section at the bottom of the worksheet why 2001 is not considered a typical year, if that is the case.

Col. A: Crop/Commodity	Enter all crops/commodities that benefit from methyl bromide in the fumigation cycle (interval between fumigations) beginning with the treatment of methyl bromide in 2001. If multiple crops are grown during the interval between fumigations (e.g. tomatoes followed by peppers in a single growing season, or strawberries followed by lettuce over 2 or 3 years) include all of the crops during the entire interval. See the Fumigation Cycle Worksheet for a comprehensive definition of the fumigation cycle. If someone other than the applicant benefits from the application of methyl bromide in the fumigation cycle and you do not have the quantitative data for the crops grown on the same land, please indicate so in the comments section below.
Col. B: Price Factors	Enter factors that determine prices (e.g., grade, time, market). If you received different prices for your crop/commodity as a result of quality, grade, market (e.g. fresh or processing), timing of harvest, etc., you may itemize by using more than one row. Itemize or aggregate these factors to the extent appropriate in making the case that the use of methyl bromide affects these price factors.
Col. C: Unit of Crop/Commodity	Enter the unit of measurement for each crop/commodity.
Col. D: Crop/Commodity Yield	Enter the number of units of crop/commodity produced per area for that price factor.
Col. E: Price	Enter average 2001 prices received by the users for that crop/commodity and price factor.
Col. F: Revenue	Revenue is automatically calculated using the data you entered for yield and price. If revenue is not equal to yield times price, you may override the formula and enter a different revenue amount. Please explain why this revenue amount is different in the comment section below.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F
Crop/Commodity	Price Factors (grade, time, market)	Unit of Crop/Commodity (e.g., pounds, bushels)	Crop/Commodity Yield (Units per area)	Price (per unit of crop/commodity)	Revenue (per area)
Pine	Species and size	1000 trees	631/acre	\$ 40.00	\$ 25,240.00
Longleaf	Size	1000 trees	343/acre	\$ 60.00	\$ 20,580.00
Hardwood	Species and size	1000 trees	197/acre	\$ 250.00	\$ 49,250.00
					\$ 0.00
					\$ 0.00
Total Revenue/Nursery					\$1.29 Million

Comments:

Total revenue is calculated for an "average" nursery according to Table 2c.

Table 2c. Calculation of the gross revenue for a "representative user" nursery in 2001.

Crop	Production	Acres	Value/acre	Revenue
Pines	25.0 Million	40.0	\$25,240	\$1.01 Million
Longleaf	0.5	1.5	\$20,580	\$0.03
Hardwoods	1.0	5.0	\$49,250	\$0.25

TOTAL REVENUE

\$1.29 Million

Worksheet 2-D. Methyl Bromide - Use and Costs for 2001

If a consortium is submitting this application, the data in Cols. B, C, D, and E should reflect the *representative use* in the consortium. The data in Col. F should reflect the *actual* area treated by all users in the consortium.

If the methyl bromide is custom applied then put the cost per area in Column G and fill in the average lb ai of methyl bromide applied per area (Col B) and the Total Actual Area Treated (Col F).

If 2001 was not a typical year for the individual or for the representative user of a consortium, the applicant may provide additional data for a different year. However, all applicants must complete this worksheet for the year 2001 regardless. If you provide an additional year's data, please explain in the comment section at the bottom of the worksheet why 2001 is not considered a typical year.

Col. A: Formulation of Methyl Bromide

Enter the appropriate data in Col B-G for each formulation, if known, and/or the totals and averages for all formulations of methyl bromide. If you just enter data in the bottom row in the table (All formulations of methyl bromide), please describe in the comments, the relative usage of the various formulations, to the extent known.

Col B: Average lbs. active ingredient (ai) of Methyl Bromide Applied per Area

Enter the average pounds active ingredient (ai) of methyl bromide applied per area.

Cols. C, D, E, G: Prices and Costs

Enter the average price per pound active ingredient (ai) of methyl bromide in Col. C and the average cost of applying methyl bromide per area treated in Col. D. In Col. E, enter the average other costs per area associated with applying methyl bromide (e.g., tarps). Column G will be calculated automatically using the values you entered in columns B-E. If methyl bromide is custom applied, enter the cost per area in Col. G and fill in Cols. B and F.

Col. F: Actual Area Treated

Enter the **actual** area treated. Note: This number should be the total area treated by all users in the consortium.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F	G
Formulation of Methyl Bromide	Lb. ai of Methyl Bromide Applied per Area (2001 Average)	Price per lb. ai of Methyl Bromide (2001 Average)	Cost of Applying Pesticide per Area (2001 Average)	Other MBr Costs (e.g. tarps, etc.) per Area (2001 Average)	Total Actual Area Treated in the Consortium	Cost per Area
over 95% methyl bromide	392	\$ 2.68	\$400		975 ac	\$1,450/ac
75% methyl bromide, 25% chloropicrin						
67% methyl bromide, 33% chloropicrin	248	\$ 2.68	\$400	\$ 385.00	646 ac	\$1,450/ac
50% methyl bromide, 50% chloropicrin				(chloropicrin)		
90% methyl bromide, 10% chloropicrin						
__% methyl bromide, __% chloropicrin						
All formulations of methyl bromide	335*	\$ 2.68	\$400		1621 ac	\$1,450/ac

Comments:

*Average from worksheet 2A.

Worksheet 2-E. Methyl Bromide - Other Operating Costs for 2001**Do not include methyl bromide costs.**If a consortium is submitting this application, the data for this table should reflect a **representative user**.

Enter all operating costs except methyl bromide costs incurred during the fumigation cycle (interval between fumigations) beginning in 2001. See the Fumigation Cycle Worksheet for a comprehensive definition of the fumigation cycle. Enter these costs in Col B for custom operations, or in Col C and D for operations done by user.

Submit crop budgets for each crop, if available. You may submit crop budgets electronically or in hard copy. If your costs are significantly different than the crop budgets, please explain in the comments.

Col A: Operation	Identify in Col A the operations (except methyl bromide) to which the costs apply. For growers, these operations should include but are not limited to (1) prepare soil, (2) fertilize, (3) irrigate, (4) plant, (5) harvest, (6) other pest controls, etc. You must include all other operating costs.
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Col B: Custom Operation Cost	If you incur custom operation costs, enter those costs in Col. B.
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Col C: Material Cost per Area	If you do not incur custom operation costs, enter the material cost per area.
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Col D: Labor Cost per Area	If you do not incur custom operation costs, enter the labor cost per area.
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Col E: Total Cost per Area	The total cost per area is calculated automatically from the values you enter in Cols. C and D.
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Col F: Typical Equipment Used	Identify the typical equipment used for operations done by user. Please be specific, such as tractor horsepower. No cost data is required in this column.
--------------------------------------	---

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F
Operation	Custom Operation Cost per Area	Operation Done by User			
		Material Cost per Area	Labor Cost per Area	Total Cost per Area	Typical Equipment Used
Soil Preparation		\$ 592.00	\$ 573.00	\$ 1,165.00	
Sowing		\$4,458.00	\$ 550.00	\$ 5,008.00	
Maintenance		\$1,061.00	\$1,412.00	\$ 2,473.00	
Fertilization, Pest Control, pruning, etc.					
Harvest and Storage		\$3,683.00	\$ 897.00	\$ 4,580.00	
Total Custom per Area			User Total per area	\$13,226.00	

1)
The consortium does not typically seek nor maintain cost data for member nurseries. In fact, anti-trust concerns make it difficult to even discuss costs and pricing. The numbers we are submitting in Worksheet 2-E and 2-F have been provided to us by one of the consortium members and should be generally representative of actual costs.

2)
Numbers used in Worksheet 2-E are for a typical pine seedling nursery. In the case of Lingleaf pine and hardwood production, the costs for "harvest" would be approximately double this amount (i.e. \$9,160).

3)
Note on typical equipment used:

Soil Preparation:	Typical farm tractor and implements
Sowing:	Highly specialized machine sowers are used to sow genetically improved seed. Power supplied by farm tractor.
Maintenance	Standard tractor drawn boom sprayers. Implements for fertilization, top and root pruning are specially designed for forest tree nurseries.
Harvest	Highly mechanized harvesting operation using specially designed seedling lifters. Seedlings placed in cold storage until shipped to planting site.

Worksheet 2-F. Methyl Bromide Fixed and Overhead Costs in 2001

If a consortium is submitting this application, the data for this table should reflect a **representative user**.

Enter **all** fixed and overhead costs incurred during the fumigation cycle (interval between fumigations) beginning in 2001. See the Fumigation Cycle Worksheet for a comprehensive definition of the fumigation cycle.

Col A: Cost Item	Identify in Col. A the cost items. These items should include, but are not limited to: (1) land rent, (2) interest, (3) depreciation, (4) management, and (5) overhead such as office and administration.)
Col B: Description	Please describe the cost in more detail.
Col C: Allocation Method	Please describe how you estimated the portion of total fixed cost of the farm or entity that applies to this crop/commodity.
Col D: Cost per Area	Enter the cost per area of methyl bromide treated.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D
Cost Item	Description	Allocation Method	Cost per Area
Labor and Labor Related	Managerial and Administrative salaries and benefits		\$2,442.99
Travel	Travel Expenses, Business Meals, Conferences		\$199.49
Advertising			\$92.56
Postage	FedEx, UPS, and regular mail charges		\$65.10
Communications	Telephones, Cellular Phones		\$201.30
Data Processing			\$44.12
Computer Hardware	Computers, printers, etc.		\$31.16
Rentals-Tangible Properties	Machine Rentals		\$49.06
Rentals-Real Property	Office Rental		\$177.94
Vehicle Lease Expenses	Auto Lease and Heavy Equipment		\$870.48
Dues and Assessments	Trade Association Dues and Contributions		\$14.08
Publications	Trade Magazine Subscriptions		\$1.97
Meetings			\$22.93
Taxes	Sales and Property Taxes		\$398.37
Depreciation	Capitalized Interest and Plant Depreciation		\$1,759.79
Legal Settlements	Company Legal Bill		\$207.96
Supplies and Equipment	Managerial and Administrative Supplies		\$517.87
Other Income/Expenses			\$148.05
Utilities	Water and Electricity		\$553.89
Allocations and Transfers	Corporate and Division Overhead		\$282.35
		Total	\$8,081.46

Comments:

Worksheet 2-A. Methyl Bromide - Use 1997-2000

If a consortium is submitting this application, all data should reflect the **actual** data for the consortium.

Col A: Formulation of Methyl Bromide	Enter the appropriate data in Col B-M for each formulation, if known, and/or the totals and averages for all formulations. If you enter only the total and averages for all formulations in the last row of the table, please describe in the comments section the formulations typically used, or the approximate proportions of the formulations used.
Col B, E, H, K: Actual Area Treated	Enter the total actual area treated. Note: This number should be the <u>total actual</u> area treated by the individual user or total actual area for the entire consortium, for the year indicated.
Col C, F, I, L: Actual Total lbs. ai of Methyl Bromide Applied	Enter the actual total pounds active ingredient (ai) of methyl bromide applied. Note: This number should be the total pounds ai applied by the individual user or the entire consortium, for the year indicated.
Col D, G, J, M: Actual Average lbs. ai Applied per Area	The average application rates in pounds ai of methyl bromide per area are automatically calculated from the previous 2 columns.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F	G	H	I	J	K	L	M
Formulation of Methyl Bromide	1997			1998			1999			2000		
	Total Actual Area Treated	Actual Total lbs. ai of Methyl Bromide Applied	Average lbs. ai Applied per Area	Total Actual Area Treated	Actual Total lbs. ai of Methyl Bromide Applied	Average lbs. ai Applied per Area	Total Actual Area Treated	Actual Total lbs. ai of Methyl Bromide Applied	Average lbs. ai Applied per Area	Total Actual Area Treated	Actual Total lbs. ai of Methyl Bromide Applied	Average lbs. ai Applied per Area
over 95% methyl bromide										975	382,200	392
75% methyl bromide, 25% chloropicrin												
67% methyl bromide, 33% chloropicrin										646	160,208	248
50% methyl bromide, 50% chloropicrin												
90% methyl bromide, 10% chloropicrin												
__% methyl bromide, __% chloropicrin												
All formulations of methyl bromide										1621	542,408	335

Comments:**Methyl bromide Use 1997-2000**

The basic mandate of our consortium has been research and technology transfer. As such we have not historically kept records of seedling production or methyl bromide use numbers. We do have, however, seedling production inventories published by the U.S. Forest Service. More importantly, the Consortium has data for the year 2000, which was obtained by surveying consortium members. We see no reason that annual Methyl bromide use rates will vary a great deal and it can be assumed that use rates for 1997 to 1999 will be similar to that of the year 2000. Below is the calculated methyl bromide use by crop type.

Table 2a. Southern Forest tree nursery use of methyl bromide in the year 2000 by crop type.

Species	Production (millions)	Trees/acre	Production Acres	Fumigated Acres
Pines	1,670	631,000	2,646	1,323
Longleaf	30	343,000	87	44
Hardwood	50	196,000	254	254
TOTALS			2,987	1,621

Worksheet 3. Alternatives - Feasibility of Alternative Pest Control Regime

Purpose of Data on Alternative Pest Control Regimens: To estimate the loss as a result of not having methyl bromide available. EPA needs to compare data (yields, crop/commodity prices, gross revenues and costs) on the use of methyl bromide and alternative pest control regimens.

Complete each of the worksheets below (3-A, 3-B, 3-C, and 3-D) for each alternative pest control regimen listed in the "U.S. Matrix" for chemical controls (www.epa.gov/ozone/mbr/cueqa.html) and the "International Matrix" for non-chemical pest controls (www.epa.gov/ozone/mbr/cue). Each worksheet contains a place holder in the title for you to insert the name of the specific alternative pest control regimen addressed. You should add additional worksheets as required. Please add a number designation to each worksheet title to indicate a different alternative. For example, for the first alternative pest control regimen label the worksheets as 3-A(1), 3-B(1), 3-C(1), and 3-D(1). For the second alternative pest control regimen label the worksheets 3-A(2), 3-B(2), 3-C(2), and 3-D(2).

Enter all alternative pesticides and pest control methods (and associated cost and yield data) that would replace one treatment of methyl bromide throughout the fumigation cycle. See the fumigation cycle worksheet for a comprehensive definition.

Worksheet	Title	
3-A	Alternatives - Technical Feasibility	This form is used to obtain information on the chemical alternatives identified by the Methyl Bromide Technical Options Committee (MBTOC) that are registered for use in the United States, as well as the non-chemical alternatives identified by the MBTOC. Applicants must address the technical feasibility of all the chemical and non-chemical alternatives identified on the list.
3-B	Alternatives - Pest Control Regimen Costs	This form is used to estimate the cost of using alternative pest control regimens.
3-C	Alternatives - Crop/Commodity Yield and Gross Revenue	This form is used to estimate the crop/commodity yields and gross revenues when using alternative pest control regimens.
3-D	Alternatives - Changes in Other Costs	This form is used to estimate change in any other costs as a result of using the alternatives.

Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide

In this worksheet, you should address why an alternative pest management strategy on the list (see previous page) is or is not effective for your conditions. This worksheet contains 9 questions. You must complete one copy of worksheet 3-A for each research study you use to evaluate a single methyl bromide alternative. Use additional pages as need.

For worksheet 3-A you must complete one worksheet for each alternative, for each research study addressed. Please number the worksheets as follows. For the same alternative, first research study, label the worksheet 3-A(1)(a). For the same alternative, second research study, label the worksheet 3-A(1)(b). For the first alternative, third research study, label the worksheet 3-A(1)(c). For the second alternative, first research study, label the worksheet 3-A(2)(a). For the second alternative, second research study, label the worksheet 3-A(2)(b).

When completing Section II, if you cite a study that is on the EPA website, you only need to complete questions 1, 5, and 8.

Summarize each of the research studies you cite in the Research Summary Worksheet.

If you prefer, you may provide the information requested in this worksheet in a narrative review of one or more relevant research reports. The narrative review must reply to Section I and questions 1 through 8 in Section II. A Research Summary Worksheet of relevant treatments should be provided for each study reviewed.

BACKGROUND

EPA must consider whether alternative pest control measures (pesticide and non-pesticidal, and their combination) could be used successfully instead of methyl bromide by crop and circumstance (geographic area.) The Agency has developed a list of possible alternative pest control regimens for various crops, which can be found at <http://www.epa.gov/ozone/mbr> or by calling 1-800-296-1996.

There are three major ways you can provide the Agency with proof of your investigative work.

- (1) Conduct and submit your own research
- (2) Cite research that has been conducted by others
- (3) Cite research listed on the EPA website

Whether you conduct the research yourself or cite studies developed by others, it is important that the studies be conducted in a scientifically sound manner. The studies should include a description of the experimental methodology used, such as application rates, application intervals, pest pressure, weather conditions, varieties of the crop used, etc. All results should be included, regardless of outcome. You must submit copies of each study to EPA unless they are listed on the Agency website.

The Agency has posted many research studies on a variety of crops on its website and knows of more studies currently in progress. EPA will add studies to its website as they become publicly available. You are encouraged to review the EPA website and other websites for studies that pertain to your crop and geographic area.

In addition, EPA acknowledges that, for certain circumstances, some alternatives are not technically feasible and therefore no research has been conducted (i.e. solarization may not be feasible in Seattle). You should look at the list of alternatives provided by the Agency and explain why they cannot be used for your crop and in your geographic area.

Use additional pages as needed.

Alternative: Basamid & Metam-sodium

Study: Many

Section I. Initial Screening on Technical Feasibility of Alternatives

1. Are there any location-specific restrictions that inhibit the use of this alternative on your site?

- 1a. Full use permitted X
- 1b. Township caps
- 1c. Alternative not acceptable in consuming country
- 1d. Other (Please describe)

If use of this alternative is precluded by regulatory restriction for all users covered by this application, the applicant should not complete Section II.

Worksheet 3-A. Alternatives - Technical Feasibility of Alternatives to Methyl Bromide**Section II. Existing Research Studies on Alternatives to Methyl Bromide**

1. Is the study on EPA's website? Yes _____ No X

1a. If not on the EPA website, please attach a copy.

The consortium has conducted a great deal of research seeking a cost effective alternative to methyl bromide for the production of bareroot forest tree nursery stock in the southeastern United States. The alternatives tested include a variety of chemicals either alone or in combination, using varying application methods, as well as high temperature water, and plant growth promoting rhizobacteria. A complete list of these studies with their location and treatments tested can be found in the Appendix at the end of Worksheet 3. A number of these studies have been included in this application. None are currently on the EPA website. Should the EPA elect to place any of these studies on their website, however, we have no objection.

2. Author(s) or researcher(s)

Most of the consortium research into methyl bromide alternatives has been done by Dr. William A. Carey with occasional collaboration from other scientists.

3. Publication and Date of Publication

A large number of studies have been conducted since 1993. These have been published in a variety of formats. Some are reported in refereed scientific journals, others have been internal to the consortium. A list of published reports on methyl bromide substitution research is provided in the Appendix at the end of this worksheet.

4. Location of research study

Numerous studies geographically distributed throughout the southeastern United States.

5. Name of alternative(s) in study. If more than one alternative, list the ones you wish to discuss.

As requested by the EPA, we will address only Basamid (dazomet) and metam-sodium as alternatives.

6. Was crop yield measured in the study? Yes X No _____

Crop yield is invariably measured in consortium studies.

7. Describe the effectiveness of the alternative in controlling pests in the study.

The Auburn University Southern Forest Nursery Management Cooperative has devoted considerable resources to the search for an economically and technically feasible alternative to methyl bromide. (See Worksheet 5). A number of chemical and non-chemical alternatives have been tried and a large volume of research data and analysis has been generated. A list of these studies is provided at the end of this worksheet and are cited in the discussions below. The Cooperative has looked intensively at both Basamid and metam-sodium as methyl bromide substitutes. *Studies have shown both Basamid and metam-sodium to be inadequate alternatives to methyl bromide for controlling pests under our circumstances.*

BASAMID

a. Basamid provides poor weed control.

Weed control is essential for the production of quality bareroot planting stock. Without good weed control, seedling size is compromised and this translates into decreases in survival and growth when outplanted during plantation establishment. (See Worksheet 3-D for a more complete discussion of the long-term economical impact of a decrease in seedling quality). Studies have shown Basamid to be one of the worst compounds regarding *Cyperus* spp. control in nursery beds (3, 5) [NOTE: Citations provided in "List of References" in the Appendix at the end of this worksheet]. This poor weed control results in a decrease in seedling quality or an increase in herbicide use and/or handweeding costs, with a subsequent increase in seedling cost.

b. Basamid has been inconsistent regarding impact on seedling size.

Methyl bromide consistently produces larger seedlings compared to non-fumigated soil. While in some studies Basamid fumigation treatments has produced seedlings of a size comparable to that of methyl bromide, there have been other studies where Basamid treatment resulted in smaller lower quality seedlings (4, 5). This effect appears to be independent of weed pressure. This inconsistency has also been observed by nursery managers that have operationally used Basamid.

c. Basamid has been shown to have long-term negative impact on certain soil microorganisms.

Studies have shown that populations of the soil fungi *Trichoderma* take much longer to recover after Basamid applications when compared to other fumigants, including methyl bromide (6, 17, 21). The impact of long-term use of Basamid on *Trichoderma* populations is unknown, but the implications are disturbing as *Trichoderma* are one of the most common classes of soil fungi and are important to a healthy rhizosphere.

d. Basamid has outgassed and resulted in damage to surrounding seedlings.

The active ingredient in Basamid is methyl-isothiocyanate (MITC) gas. Upon activation with water, this gas provides the fumigation effect. There has been at least one report of outgassing from an application of Basamid where a significant number of seedlings in adjacent areas were damaged (20). Please see the following section on metam-sodium for a more complete discussion of this topic.

METAM-SODIUM

a. Metam-sodium has serious problems with human and environmental safety

Early studies with metam-sodium showed it most effective as a fumigation treatment when combined with chloropicrin (6, 7). Metam-sodium/chloropicrin combinations provided pest control and seedling growth response equivalent to Methy-bromide. However, when this treatment was moved from small research-scale applications to field-scale applications, the results were disastrous. We have documented cases of seedling damage from outgassing events at nurseries in Louisiana, Texas, Arkansas, Oregon (20), and Montana (2). There are several cases where metam-sodium was applied as a fumigation treatment and subsequently outgassed and killed a significant number of seedlings. In the case of the Texas nursery, a 1999 outgassing event resulted in the loss of approximately 20 million seedlings and a law suit for the applicator. In addition, and more importantly, the gas typically follows topography and poses a threat to anyone in the path of the gas cloud. Warning letters and photographs of the damage are provided in the Appendix at the end of this worksheet.

b. Metam-sodium alone results in poor nutsedge (*Cyperus* spp) control

As a stand alone fumigation treatment, metam-sodium has been shown to provide poor weed control under forest tree nursery conditions (3, 14, 18, 24). Poor weed control results in a decrease in seedling quality, increased herbicide use, and/or increased handweeding and subsequently increased seedling cost.

c. Metam-sodium needs to be rotovated into the soil for even distribution

The use of mechanical rototillers have two serious disadvantages. The first is a possible decline in soil quality as a result of intense mechanical tillage. In at least one consortium trial there was an observed decline in nursery soil quality caused by damaged soil structure. There is a tendency for a "plow pan" to form at the bottom of rototilled soil, with soil tilth and structure altered such that drainage and aeration are negatively affected (1). The second is the additional time required for this operation. Metam-sodium fumigation and rototilling increases application time by 300% over methyl bromide.

8. Discuss how the results of the study apply to your situation. Would you expect similar results? Are there other factors that would affect your adoption of this tool?

How do the results of these studies apply to our situation?

These studies apply precisely to the conditions of the consortium as they are done on consortium lands, under the exact field conditions where fumigation is and will be practiced, distributed over the entire geographic range of the consortium and repeated over several years.

Worksheet 3-B. Alternatives - Pest Control Regimen Costs for Alternative

Metam-sodium

If a consortium is submitting this application, the data for this table should reflect a representative user.

Col. A: Name of Product and Non-chemical Control	Enter all alternatives and non-chemical pest control that would replace one treatment of methyl bromide throughout the fumigation cycle. See the Fumigation Cycle Worksheet for a comprehensive definition of the fumigation cycle. If multiple crops are grown If someone other than the applicant previously benefited from the application of methyl bromide in the fumigation cycle and you do not have the quantitative data for the crops grown on the same land, please indicate so in the comments section below.
Col. B: Target Pests	Be as specific as possible regarding the species or classes of pests controlled by the active ingredient or pesticide product.
Col. C: Active Ingredients	Use one row for each active ingredient (ai). For example, if a product contains 2 ai's use 2 rows for that product. Once a row is completed for a given product, then only Col. B (if applicable), C, and E need to be completed for additional rows regarding
Col. D: Formulation	Enter the formulation or the % of active ingredient.
Col. E, F, G: Application Rate	As a cross check, EPA is requesting both the amount of active ingredient in Col. E and product applied per area in Col. F. Indicate the unit of the product in Col. G.
Col. H, I, J: Prices and Costs	Use 2001 prices and costs. If the product is custom applied you may enter the total cost in the last column (Col. M) and override the formula. If a pesticide is applied by the user, enter the price of the product in Col. H and the cost of applying it in Col. I. Enter any other costs associated with applying this product in Col. J, specifying what they are in the comments section at the bottom of this sheet.
Col. K: Area Treated	Enter the area receiving at least one application of the pesticide.
Col. L: # of Applications per Year	Enter the number of applications in a fumigation cycle comparable to methyl bromide for this alternative pest control regimen. Since this number is an average, it does not need to be a whole number.
Col. M: Cost per Area in 2001 Dollars	Enter the cost per area in 2001 dollars. Col. M will be calculated automatically using the data you have entered for a chemical pest control, or, the formula in Col. M can be overridden if the cost per area is known because the product was custom applied
Non-chemical Control	Enter data near the bottom of the form. Identify the control in Col. A. Enter the target pests in Col. B. Describe the non-chemical pest control Col. B-L. Enter the costs in Col. M in 2001 dollars.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F	G	H	I	J	K	L	M
Name of Product	Target Pests	Active Ingredients (ai) In Product	Formulation of Product	Application Rate			Price per Unit of the Product	Cost of Applying Pesticide per Area	Other Costs per Application per area	Area Treated at Least Once	# of Applications per Year	Cost per Area (2001\$)
				lbs. ai per Area per Application	Units of product per Area per Application	Product Unit (e.g., lbs., gals)						
Tarped metam-sodium (vapam sectagon)	weeds/fungi	MITC	42%	210 lbs	60	gallons					1	\$ 2,000.00
Non-Chemical Pest Control	Target Pests	Description										Cost/area
Control P												
											Total	\$ 2,000.00

Comments:

If you do not have the quantitative data for additional crops grown on the same land, please indicate so in the comment section.

Works/ 3-B. Alternatives - Pest Control Regimen Costs for Alternatives

Basamid

If a consortium is submitting this application, the data for this table should reflect a representative user.

Col. A: Name of Product and Non-chemical Control	Enter all alternatives and non-chemical pest control that would replace one treatment of methyl bromide throughout the fumigation cycle. See the Fumigation Cycle Worksheet for a comprehensive definition of the fumigation cycle. If multiple crops are grown during the interval between fumigations (e.g. tomatoes followed by peppers in a single growing season, or strawberries followed by lettuce over 2 or 3 years) include all of the pesticides that replace methyl bromide for the entire interval. Do not include pesticides that are used along with methyl bromide—enter only the additional pest control if methyl bromide were not available. If someone other than the applicant previously benefited from the application of methyl bromide in the fumigation cycle and you do not have the quantitative data for the crops grown on the same land, please indicate so in the comments section below.
Col. B: Target Pests	Be as specific as possible regarding the species or classes of pests controlled by the active ingredient or pesticide product.
Col. C: Active Ingredients	Use one row for each active ingredient (ai). For example, if a product contains 2 ai's use 2 rows for that product. Once a row is completed for a given product, then only Col. B (if applicable), C, and E need to be completed for additional rows regarding the same product.
Col. D: Formulation	Enter the formulation or the % of active ingredient.
Col. E, F, G: Application Rate	As a cross check, EPA is requesting both the amount of active ingredient in Col. E and product applied per area in Col. F. Indicate the unit of the product in Col. G.
Col. H, I, J: Prices and Costs	Use 2001 prices and costs. If the product is custom applied you may enter the total cost in the last column (Col. M) and override the formula. If a pesticide is applied by the user, enter the price of the product in Col. H and the cost of applying it in Col. I. Enter any other costs associated with applying this product in Col. J, specifying what they are in the comments section at the bottom of this sheet.
Col. K: Area Treated	Enter the area receiving at least one application of the pesticide.
Col. L: # of Applications per Year	Enter the number of applications in a fumigation cycle comparable to methyl bromide for this alternative pest control regimen. Since this number is an average, it does not need to be a whole number.
Col. M: Cost per Area in 2001 Dollars	Enter the cost per area in 2001 dollars. Col. M will be calculated automatically using the data you have entered for a chemical pest control, or, the formula in Col. M can be overridden if the cost per area is known because the product was custom applied.
Non-chemical Control	Enter data near the bottom of the form. Identify the control in Col. A. Enter the target pests in Col. B. Describe the non-chemical pest control Col. B-L. Enter the costs in Col. M in 2001 dollars.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F	G	H	I	J	K	L	M
Name of Product	Target Pests	Active Ingredients / (ai) in Product	Formulation of Product	Application Rate			Price per Unit of the Product	Cost of Applying Pesticide per Area	Other Costs per Application	Area Treated at Least Once	# of Applications per Year	Cost per Area (2001\$)
				lbs. ai per Area per Application	Units of product per Area per Application	Product Unit (e.g., lbs., gals)						
Basamid	weeds/fungi	MITC	98%	350/ac	343	lbs					1	\$ 2,500.00
												\$ 0.00
												\$ 0.00
												\$ 0.00
												\$ 0.00
												\$ 0.00
												\$ 0.00
												\$ 0.00
												\$ 0.00
												\$ 0.00
												\$ 0.00
												\$ 0.00
												\$ 0.00
												\$ 0.00
												\$ 0.00
Non-Chemical Pest Control	Target Pests	Description										Cost/Area
											Total	\$ 2,500.00

Comments:

If you do not have the quantitative data for additional crops grown on the same land, please indicate so in the comment section.

Basamid and Metam-sodium

The purpose of this worksheet is to identify the gross revenue for units (crop, commodity, structure) when using an alternative compared to gross revenue when using methyl bromide. Post-harvest and structural users may modify this form to accommodate differences in operations when providing gross revenue data.

Area is defined below as follows:

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

Comments:

Gross Revenue of Alternatives

The same "representative user" was used in Worksheet 3-C as defined in Worksheet 2-C in terms of annual crop production and area. Since both methyl bromide alternatives provide the same results in our research trials, the estimation of gross revenue for a representative user is the same for both compounds.

Research has shown that alternatives provide conservatively 2.2 fewer seedlings per square foot of crop area than does methyl bromide. It is essential, however, to consider indirect effects (covered in Worksheet 3-D) to accurately assess the impact of the loss of methyl bromide.

Table 3c. Calculation of the gross revenue for a "representative user" nursery in 2001 when using alternative fumigation treatments.

<u>Crop</u>	<u>Production</u>	<u>Acres</u>	<u>Value/acre</u>	<u>Revenue</u>
Pines	25.0 Million	40.0	\$23,000	\$0.920 Million
Longleaf	0.5	1.5	\$16,440	\$0.037
Hardwoods	1.0	5.0	\$39,000	\$0.195

TOTAL REVENUE

\$1.152 Million

Worksheet 3-D. Alternatives - Changes in Other Costs for Alternative:

Basamid and Metam-sodium

If a consortium is submitting this application, the data for this table should reflect a *representative user*.

Enter data only for costs (other than the cost of alternative pest control) that change as a result of using the alternatives instead of methyl bromide. Enter the whole cost, not just the incremental changes. Enter the cost in Col. B for custom operation costs, or in Col. C and D for operations done by user.

Col. A: Operation or Cost Item	Identify the operations or cost items that change as a result of not using methyl bromide.
Col. B: Custom Operation Cost	Enter custom operation costs that change in Col. B.
Col. C, D, E: Costs per Area	Enter in Col. C and D, material and labor costs per area that change for operations done by user. The total cost per area is calculated automatically from the values you enter in Cols. C and D.
Col. F: Typical Equipment Used	Identify changes in the typical equipment used by the user as a result of not using methyl bromide. Please be specific such as tractor horsepower. No cost data are required in this column.

Area is defined below as follows for each user: acres for growers, cubic feet for post-harvest operations, and square feet for structural applications.

A	B	C	D	E	F
Operation or Cost Item	Custom Operation Cost per Area	Operation Done by User			Typical Equipment Used
		Material Cost per Area	Labor Cost per Area	Total Cost per Area	
SEE COMMENTS					
Total Custom per Area			User Total per area		

Comments:

Alternatives: Changes in Other Costs for Alternative

There are significant indirect costs associated with the loss of methyl bromide fumigation in forest tree nurseries. As pointed out in Section 3-A question 7, we do not currently have a viable substitute for methyl bromide fumigation. What will be the "market disruption" to the forest tree nursery business, and more importantly, to the forest products industry, with the loss of methyl bromide? In fact, the most serious market disruptions will not occur from an increase in the cost of soil fumigation, they will be the result of a decrease in planting stock quality and an increase in planting stock price. *The most serious consequences, therefore, will not be the direct effect of using a more expensive or less effective fumigation alternative, it will be the long-term and indirect effect on the reforestation program in the southeastern United States.*

Comments Continued:

Research has consistently shown fumigation with Methyl bromide in forest tree nurseries to produce the following effects:

- 1 an increase in the NUMBER of seedlings produced per unit of area (4, 5, 7, 8, 9, 10, 11, 13, 16)
- 2 an increase in the average SIZE of seedlings (4, 5, 7, 8, 9, 10, 11, 16)
- 3 an increase in WEED CONTROL (5, 6, 18)

The loss of methyl bromide, or the adoption of either metam-sodium or Basamid alternatives will cause a decrease in seedling numbers per unit of area, a decrease in average seedling size, and an increase in weed control costs.

The cost of a reduction in seedling production per unit of area.

The bed density of bareroot pine seedlings in the southeastern United States is 878,000 per acre of bed. At \$40 per 1,000 seedlings, this is a value of \$35,000 per bed acre. By increasing the number of saleable seedlings by only 1 per square foot of bed space, the value of a bed acre increases by \$1,700. This is substantially more than the historical cost of fumigation. Since methyl bromide fumigation has been shown to increase bed density by 2 to 7 seedlings per square foot, this is an increase in seedling value of \$3,400 to \$11,900 per bed acre. (We used a conservative 2.2 seedlings per square foot in Worksheet 3-C.)

The cost of a decrease in average seedling size

It has been well established that larger seedling sizes translate into increased survival and growth during reforestation. For example, plantation managers can gain one full year of growth on a plantation rotation of 20 years if they plant a seedling of 6.5 mm root collar diameter (grade 1) as opposed to a seedling of 4.5 mm diameter (grade 2). In addition, there is 5% increase in survival for the larger seedling class. Consortium data indicates the net present value of this size increase can be \$0.10 per seedling (10, 12, 22). Research has shown that fumigation can double or triple the production of grade 1 seedlings in the nursery. *When the effect of fumigation is multiplied over the 1.7 billion seedlings produced and the approximately 2 million acres planted annually in the southeastern United States, the indirect effect of nursery fumigation is truly staggering.* Unless a fumigation alternative is found that can match the cost effectiveness of Methyl bromide, this industry-wide impact of nursery fumigation on forest sustainability and productivity will be lost.

The cost of increased weed competition

Methyl bromide fumigation provides cost effective control of nutsedge (*Cyperus* spp) and its loss will result in an increase in herbicide use and/or an increase in handweeding. Surveys indicate that nurseries annually spend an average of only 368 hours handweeding. We estimate that with the loss of methyl bromide fumigation, the amount of (5, 6) handweeding may increase several fold. Although cost effective herbicides are available for forest tree nurseries, they are not effective against all weeds. We anticipate the increase in weeding costs will be sufficient to result in higher seedling prices for both pines and deciduous hardwood species. Hardwoods may in fact be more adversely effected as there are few selective herbicides labeled for hardwoods and fumigation is, in fact, the backbone of hardwood nursery weed control.

Seventy percent of all forest land in the southeastern United States is owned by non-industrial private landowners, with 20% owned by forest industry, and 10% public. Non-industrial owners are highly sensitive to the price of reforestation. Studies have shown that a relatively small increase in reforestation costs results in fewer landowners reforesting (15,19). This is particularly true for deciduous hardwood species that are usually planted for wetland restoration, wildlife, and aesthetic purposes. Given the importance of non-industrial owners on the general timber supply in the region, a reduction in reforestation efforts by this group may have serious long-term negative impacts on the sustainability of the resource. Moreover, in specific reference to industry, they also must carry reforestation costs across an entire rotation. And while they rarely opt to not reforest harvested acres, any increases in reforestation costs make them less competitive on the world market.

IN SUMMARY

The loss of methyl bromide fumigation in forest tree nurseries will have significant large scale disruptions that go well beyond the nursery. While direct effects on seedling production, seedling quality, and seedling cost may in fact be documented, the true market disruption is the indirect effect on plantation establishment and growth amplified over the millions of acres reforested every year in the region.

APPENDIX TO WORKSHEET 3

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- I. LIST OF REFERENCES CITED
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Auburn University
Southern Forest Nursery Management Cooperative

APPLICATION FOR A METHYL BROMIDE CRITICAL USE EXEMPTION
APPENDIX TO WORKSHEET 3

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School of Forestry

Southern Forest Nursery Management
Cooperative
Office of the Director

FAX: (334) 844-4873
Telephone: (334) 844-1044

January 12, 2000

To: All Nursery Coop Members

From: Ken Mc Nabb
Coop Director

Through: Coop Advisory Committee

Subject: **WARNING!!!!**
REGARDING THE USE OF THE CHLOROPICRIN / SECTAGON®
COMBINATION FOR NURSERY FUMIGATION

One of the top research priorities of the Nursery Coop has been to find a cost effective substitute for Methyl Bromide. We have devoted considerable resources and time to that purpose over the past 5 or so years. Bill Carey in particular has conducted a number of experiments throughout the geographic distribution of the Coop to compare different fumigation possibilities. Hendricks and Dale have been very supportive partners in this effort and assisted in the installation and evaluation of these various trials. Over the course of these investigations the combination of chloropicrin and Sectagon (methyl- isothiocyanate or MITC) has consistently shown itself to be the best alternative to Methyl Bromide when considering pest control (both weeds and fungi) as well as seedling response. MITC is also the active ingredient and major breakdown product of dazomet (Basamid®).

There has been a very serious problem, however, moving the chloropicrin / Sectagon treatment from the experimental phase to actual large-scale nursery field application. At least two locations within the Coop that have used this combination for field fumigation have experienced grave consequences related to post-application drift. One of these locations was the International Paper SuperTree nursery in Bullard, Texas. As a result of their experience, International Paper has asked that a letter of warning be posted to all Coop members. You will note in their letter that the fumigant drifted from the area of application and resulted in significant mortality to nearby seedlings. A similar drift problem occurred when using only dazomet at the J. Herbert Stone Nursery in 1988 (Scholtes 1989). Last November, another drift problem occurred in California after Sectagon (used alone) was applied to a 160 acre potato field. There is, of course, the possibility this type of mass drifting could be dangerous to nursery workers or neighbors.

Please review the attached letter from Rick Barham regarding chloropicrin / Sectagon fumigation. Nursery managers should be aware of the risks associated with this treatment. Liability issues should be discussed with the applicator. Bill Carey can also provide you with information regarding this fumigation treatment. Please weigh your options carefully.



Figure 1. An aerial view of seedling damage at the Bullard, Texas nursery. The fumigation (untarped metham sodium plus chloropicrin) was applied in the area in the foreground. Out-gassed chemical moved downhill toward the lake in the background



Figure 2 Closeup of the damage at the Texas nursery. View from the road toward the left in Figure 1.



Figure 3. Seedling damage at the Waynesboro, Mississippi nursery resulting from an untarped application of chloropicrin/sectagon in the fall of 1999.

INTERNATIONAL PAPER

Richard O. Barham
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Forest Resources

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December 03, 1999

Dr. Ken McNabb
School of Forestry
122 B M. White Smith Hall
Auburn University, AL 36849-5418

Dear Ken:

This letter is to notify you of a chemical burn we have suffered on approximately 20 million seedlings at our Texas SuperTree Nursery. I will explain to you in general terms what occurred. I am requesting that you distribute a copy of this letter to all the Coop. advisory members, so they will not use the same chemicals and procedures.

On November 11, Hendrix and Dail fumigated 10 acres with a chloropicrin and Sectagon mixture using a rotovate and roll procedure. Over the next several days the fumigate was released from the ground and drifted over approximately 25 acres of seedlings. By the afternoon of November 13, the seedlings started to turn brown. We have tested the photosynthetic activity of the stems and buds and there is little or no activity. The majority of the seedlings appear to be dead or dying.

This same thing happened at the Mississippi Forestry Commission's Waynesboro Nursery in October, but on a much smaller scale. No nursery should attempt to use chloropicrin and / or Sectagon without tarping it. And I feel before these chemicals are used further, we need to know how and how much of these chemicals are released when the tarp is removed.

This event points out the importance of seeking a special use permit for methyl bromide for forest tree nurseries. We need to push forward as a Coop. to achieve this goal.

If you or any of the Coop. membership would like more information, please contact me directly at 601-605-1250.

Sincerely,



Richard O. Barham

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Auburn University
Southern Forest Nursery Management Cooperative

APPLICATION FOR A METHYL BROMIDE CRITICAL USE EXEMPTION
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LIST OF RESEARCH TRIALS ESTABLISHED BY THE AUBURN
UNIVERSITY SOUTHERN FOREST NURSERY MANAGEMENT
COOPERATIVE TO SEARCH FOR A METHYL BROMIDE ALTERNATIVE

<u>YEAR</u>	<u>LOCATION</u>	<u>TREATMENTS</u>
1994	Summerville, SC Statesboro, GA	MC33, Basamid, chloropicrin
1994	Summerville, SC	MC33, Basamid, chloropicrin, Triform Sectagon/chloropicrin, Basamid/chloropicrin
1994	New Kent, VA	MC33, Basamid, Triform, chloropicrin
1994	Statesboro, GA	MC33, Triform, chloropicrin, bio-amendments
1994	Glennville, GA	MC2, MC33, Basamid
1995	Winona, MS	MC33, Triform, chloropicrin, Sectagon Sectagon/chloropicrin, Basamid
1996	Camden, AL	MC33, Triform/Sectagon/chloropicrin, hot water
1996	Glennville, GA	MC2, chloropicrin. Plant Growth Promoting Rhizobacteria
1997	Tyler, TX	MC2, Triform, chloropicrin
1997	Camden, AL Swansea, SC Glennville, GA	MC2, Plant Growth Promoting Rhizobacteria
1997	Aiken, SC	Plant Growth Promoting Rhizobacteria
1997 1998	Montezuma, GA Glennville, GA Beauregard, LA	chloropicrin, chloropicrin/Sectagon, chloropicrin/Eptc, chloropicrin/Sectagon/Eptc

1998	Atmore, AL	MC33, chloropicrin, chloropicrin/Eptc all w/wo Plant Growth Promoting Rhizobacteria
1999	Glennville, GA	MC33, chloropicrin/Sectagon (variable rates chloropicrin) (numbered compound)
1999	Georgetown, MS	Chloropicrin/Sectagon (variable rates) (numbered compound)
1999	Chatsworth, GA	MC33, chloropicrin, chloropicrin/Sectagon chloropicrin/Eptc, all w/wo Plant Growth Promoting Rhizobacteria
1999	Montezeuma, GA	Chloropicrin/Sectagon (chloropicrin/numbered compound), Eptc
2000	Summerville, SC	Chloropicrin/Sectagon, Eptc (for Hardwoods)
2000	Alto, TX	Chloropicrin/Sectagon, Eptc (for Hardwoods)
2001	Statesboro, GA	Methyl Iodide, Basamid, telone, metham sodium
2001	Ashburn, GA	Methyl Iodide, Basamid, telone, metham sodium
2002	Aiken, SC	Methyl Iodide, Basamid, telone, metham sodium

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Worksheet 4. Alternatives - Future Research Plans

Please describe future plans to test alternatives to methyl bromide. (All available methyl bromide alternatives from the alternatives list should have been tested or have future tests planned.) There is no need to complete a separate worksheet for future research plans for each alternative - you may use this worksheet to describe all future research plans.

1. Name of study: Various studies

2. Researcher(s): The Auburn University Southern Forest Nursery Management Cooperative under the technical
guidance of Dr. William Carey

3. Your test is planned for: Fall 2002 and continuing

4. Location: Several locations throughout the South

5. Name of alternative to be tested:

We will continue to test methyl iodide, chloropicrin, eptc, and probably azides.

6. Will crop yield be measured in the study? Yes X No _____

7. If additional testing is not planned, please explain why. (For example, the available alternatives have been tested and found unsuitable, an alternative has been identified but is not yet registered for this crop, available alternatives are too expensive for this crop, etc.)

We will continue to actively pursue an alternative

Worksheet 5. Additional Information

1. How will you minimize your use and/or emissions of methyl bromide?

- 1a. Check all methods you will use ☐ Nothing
☒ Tarpaulin (high density polyethylene)
☐ Virtually impermeable film (VIF)
☐ Cultural practices (please specify) _____

1b. Will you use other pesticides to reduce use of methyl bromide?

Yes ☒ No ☐

If yes please specify. Increased use of herbicides in cover crops

1c. Other non-chemical methods: (please specify):

2. Do you have access to recycled methyl bromide?

Yes ☐ No ☒

If yes, how many pounds? _____ lbs.

3. Do you anticipate that you will have any methyl bromide in storage on January 1, 2005?

Yes ☐ No ☒

If yes, how many pounds? _____ lbs.

4. What is the cumulative amount spent to date by the user or consortium on research to develop alternatives to methyl bromide (beginning in 1992)?

\$ 1,266,673.00

5. Other investments, if any, made to reduce your reliance on methyl bromide. Describe each investment and its associated cost.

We are pursuing compounds that can better control problem weeds such as *Cyperus* spp.

6. Identify what factors would allow you to stop or reduce your use of methyl bromide (e.g. registration of particular pesticide; completion of research plan; capital outlay).

Only an effective alternative will reduce our use.

When do you expect these to occur?

Unknown

7. Range of acres farmed by growers included in this application? (insert number of users in each category)

☐ 0-10 acres
☐ 10-25 acres
☒ 25-50 acres
☒ 50-100 acres
☒ 100-200 acres
☐ 200-400 acres
☐ over 400 acres

Worksheet-5. Additional Information (continued)

3. Range of square feet of the area to which applicants included in this application will apply methyl bromide? (insert number of users in each category)

____ 0 - 5,000 sq. ft.
____ 5,001 - 10,000 sq. ft.
____ 10,001 - 20,000 sq. ft.
____ 20,001 - 40,000 sq. ft.
____ 40,001 - 80,000 sq. ft.
____ 80,001 - 160,000 sq. ft.
55 over 160,000 sq. ft.

Worksheet 5 Estimating the cost of Coop research into MBr alternative

The Coop. estimates that the search for alternatives to MBr have occupied a third of our research effort since 1993. With an annual operating budget of \$200,000 this would be **\$666,000**. This includes about 50% of the time for one Research Fellow and 10% and 25% respectively of two Technicians that are full time employees of the Coop but does not include the time of Auburn faculty associated with the Coop. The Contribution of Auburn University through faculty salaries of those three members closely associated with the Nursery Coop. during this period should add approximately **\$150,000**.

A substantial contribution to research but not funded by the Auburn Coop has been the efforts by Dr. Scott Enebak into potential biological methods (primarily Plant Growth Promoting Rhizobacteria research) to offset the loss of MBr. Since 1996, Dr. Enebak has generated \$300,792 in grants for his PGPR research. To those grants, Auburn has contributed \$108,000 for a full time technician and student workers who have been employed in this research for a total of **\$411,612** for PGPR and fumigation research.

The contribution of Hendrix and Dail to our research effort is calculated as **\$39,061**. This figure would not purchase the materials and labor on the open market. No commercial company would haul materials to Texas, 2,000 mile round trip, to treat half an acre for \$3,000.

The research within the Coop is highly cooperative. Nothing can be done without the cooperation of the nursery that agrees to allow the study to be placed on its production beds. It is very difficult to estimate the dollar contributions of these cooperating nurseries. For several studies the host nursery has just set the study area aside and not included it in its inventory of sold seedlings from treatment plots. In several studies seedlings from treatment plots have not been salable. The fate of seedlings within a study area often depends on market demands. In all instances we have received labor help from the host nursery. It is certain that the dollar value for this contribution is not zero, but very difficult to estimate.

We estimate cost of MBr replacement research associated with the Auburn Nursery Coop (the sum of **bold face**) figures to have been \$1,266,673 between 1993 and 2002.

I certify that all information contained in this document is factual to the best of my knowledge.

Signature _____

Date _____

Print Name _____

Title _____

5/24/02
Consortium Director

Worksheet 5. Additional Information

Information in this application may be aggregated with information from other applications and used by the United States government to justify claims in the national nomination package that a particular use of methyl bromide be considered "critical" and authorized for an exemption beyond the 2005 phaseout. Use of aggregate data will be crucial to making compelling arguments in favor of critical use exemptions. **By signing below, you agree not to assert any claim of confidentiality that would affect the disclosure by EPA of aggregate information based in part on information contained in this application.**

Signature

Ken McNabb

Date

Sept 4, 02

Print Name

Ken McNabb

Title

Consortium Director

Burden means the total time, effort, or financial resources expended by persons to generate, maintain, retain, or disclose or provide information to or for a Federal agency. This includes the time needed to review instructions; develop, acquire, install, and utilize technology and systems for the purposes of collecting, validating, and verifying information, processing and maintaining information, and disclosing and providing information; adjust the existing ways to comply with any previously applicable instructions and requirements; train personnel to be able to respond to a collection of information; search data sources; complete and review the collection of information; and transmit or otherwise disclose the information. Public reporting burden for this collection of information is estimated to average 324 hours per response and assumes a large portion of applications will be submitted by consortia on behalf of many individual users of methyl bromide. An agency may not conduct or sponsor, and a person is not required to respond to, a collection of information unless it displays a current OMB control number.

OMB Control # 2060-0482

Worksheet 6. Application Summary

This worksheet will be posted on the web to notify the public of requests for critical use exemptions beyond the 2005 phase out for methyl bromide. Therefore, this worksheet cannot be claimed as CBI.

- | | | | |
|---|---|----------------|-------------------|
| 1. Name of Applicant: | <u>Auburn University Southern Forest Nursery Mgt. Cooperative</u> | | |
| 2. Location: | <u>Auburn University, AL</u> | | |
| 3. Crop: | <u>Forest Tree Seedlings</u> | | |
| 4. Pounds of Methyl Bromide Requested | 2005 | <u>542,408</u> | |
| 5. Area Treated with Methyl Bromide | 2005 | <u>1621</u> | <u>acre</u> units |
| 6. If methyl bromide is requested for additional years, reason for request: | | | |

Crops are fumigated annually. No possible alternatives.

2006	542,408 lbs.	Area Treated	1621	acres	units
2007	542,408 lbs.	Area Treated	1621	acres	units

Place an "X" in the column(s) labeled "Not Technically Feasible" and/or "Not Economically Feasible" where appropriate. Use the "Reasons" column to describe why the potential alternative is not feasible.

[illegible]

PHYTOXICITY WITH METAM SODIUM

Robert J. Buzzo

In: Riley, L.E.; Dumroese, R.K.; Landis, T.D. (Compilers). 2002 National Nursery Proceedings - 2002. Proceedings RMRS-P-000. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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ABSTRACT

Lawyer Nursery in Olympia, Washington fall fumigated fallow nursery ground with Vapam and Telone II and Vapam and Telone C-17 from 1998 through 2001. This fumigation provided excellent results when hardwood and conifer seedlings were sown into the treated areas the following spring. Seedling crops were larger and suffered less mortality than crops sown into unfumigated ground. The fall 2001 fumigation, however resulted in significant damage to established *Pinus* crops growing adjacent to and up to 400' from the fumigation area as a result of MITC escaping from the soil into the atmosphere.

INTRODUCTION

Lawyer Nursery, Inc., of Plains, Montana, established itself on the West Coast in 1988 when the company purchased a 120-acre nursery site in Olympia, Washington. This property was developed as a forest nursery in 1970 and was operated by an industrial forest seedling producer until 1985. In 1991, the company purchased an additional 55 acres adjacent to the nursery and Lawyer Nursery currently produces an annual crop of 7-8 million bare root seedlings and transplants on the 175-acre nursery site. Lawyer Nursery in Olympia grows approximately 300 species of seed propagated woody trees and shrubs for a number of markets, including ornamentals, conservation, forestry, Christmas trees, commercial orchards, etc.

This discussion will document soil fumigation experience at Lawyer Nursery in Olympia and evaluate the effectiveness and phytotoxicity of the chemical fumigant Vapam HL.

DISCUSSION

When I came to the nursery in 1989, my recent nursery background was in forestry seedling and Christmas tree production. At that time, periodic soil fumigation with Methyl Bromide/Chloropicrin (MBC) was a standard practice in the industry. I utilized this technology in the fall of 1991 through 1993. We achieved typical results with the MBC fumigation in terms of reduced seedbed mortality and excellent weed control, but we struggled with stunted 1-0 conifers which we attributed to mycorrhizal starvation. In 1994 we sowed a fumigated field with several species of *Acer*. The subsequent poor growth was so dramatic that we discontinued the use of MBC for soil fumigation. This response of *Acer*, thought to be associated with the loss of beneficial mycorrhizae was reported by Regan in 1996. Many hardwood trees, including *Acer* associate themselves with endomycorrhizal fungi, which have spores that are only soil borne. This means that re-innocation can be a slow process if fumigation damages endomycorrhizal fungi. (Davey 1994) For the next several years, we utilized crop rotation and post plant fungicide applications to control soil borne pathogens in our seedbeds. We considered soil pathogens to be a much less formidable obstacle to seedling production than the lack of beneficial mycorrhizal fungi.

Interest in alternative chemical fumigants to MBC were studied as early as 1986 (McElroy 1986) because of the relatively high application cost of MBC, the fear of regulatory intervention, and the acute toxicity of MBC. Two chemicals, metam sodium (Soil Prep, Vapam, Metam, Nemasoll) and dazomet (Basamid) were evaluated in 1985 (Campbell and Kelpsas, 1986) and were found to perform as well as MBC in terms of seedling survival and growth. When MBC was listed as a potential ozone depleter in November of 1992 and assigned a phase out schedule by the EPA, more studies on alternative fumigation chemicals were undertaken in the South. (Carey 1994)

In 1998, Lawyer Nursery participated in a small soil fumigation trial comparing Vapam, Vapam and Telone II, Telone C-17, and Telone C-35. Telone C-17 is a combination of Telone (1-3-dichloropropene) and 17%Chloropicrin and Telone C-35 is a combination of Telone and 35%Chloropicrin. (Dow AgroSciences 1999) This 4 acre trial was done in the fall of the year and and the following spring, the area was sown with several species of deciduous and conifer crops. The performance of the crops that were sown into the fumigated ground in 1999 was quite dramatic in terms of increased seedling size and reduced seedbed mortality in the Vapam/TeloneII, plot compared to the non-fumigated control. The seedling performance in the Telone C-17 and Telone C-35 plots was better than the unfumigated control, but not as good as the plot with the Vapam. It was my feeling that Vapam reduced soil pathogens without eliminating beneficial mychorrizae fungi. Based on the results of this trial, we hired a contractor to treat 13 acres with Vapam/Telone II in 1999. The rates were 30 gal/A for Vapam and 24 gal/A for Telone II.

We spring sowed both deciduous and conifer crops into the fall 1999 fumigated soil and the results were again very promising The seedlings in the fumigated soil sized up better and we noticed less seedbed mortality in the fumigated areas compared with seedling crops in non fumigated areas. In the fall of 2000 we increased the Vapam rate to 60 gal/A in an effort to improve weed control. We fumigated 18 acres that year with Vapam and Telone; the Telone rate remained at 24 gal/A. The performance of the seedlings planted into the fields fumigated in the fall of 2000 was again very dramatic. We continued to see good size and reduced seedbed mortality. Weed control was erratic, however. In some of the fumigated areas, the population of weed seeds was significantly reduced, while in others, we did not see any significant reduction in the number of weeds. In 2001, we decided to use the combination of Vapam at 60 gal/A and Telone C-17 at 23 gal/A instead of Telone II. We fumigated 28 acres in the fall of 2001. The seedbeds in the fumigated areas continued to show the same results we had seen the previous two growing seasons in fumigated soil.

In 2002 we sampled soil in deciduous 1-0 seedbeds 10 months after fumigation to see if a soil pathogen assay would confirm what we saw when we visually compared crops in fumigated soil with similar crops sown in non

fumigated soil. These results are summarized in Table 1 and they confirm that Vapam is effective at reducing the levels of *Pithium* and *Fusarium*. It is my feeling that Vapam reduces pathogen levels without severely impacting mycorrhizal fungi levels and this is what made this material so appealing to Lawyer Nursery. I do not have data other than crop performance to support this hypothesis.

Weed control with Vapam continued to be erratic; in some areas the chemical had reasonable efficacy on weed seeds, while in others we saw little, if any, affect on weed control.

Vapam HL, or metam-sodium (4.26lb ai/gal) is a dithiocarbamate aqueous sodium salt. The Stauffer Chemical Company first patented Vapam in 1956. (Herbicide Handbook 2002) Fumigation of soil with metam-sodium was discovered in 1950 and it was reported as early as 1962 as a soil fumigant in a forest nursery. (Hodges 1962) Metam sodium is considered to be a MITC generator because it is quickly broken down in moist soil to methylisothiocyanate (MITC). MITC is toxic to nematodes, fungi, bacteria and insects in the soil. (Herbicide Handbook 2002) This chemical gained some notoriety outside of the nursery industry in July of 1991 when a train derailment in Northern California resulted in the spill of approximately 13,000 gallons of Vapam into the Upper Sacramento River. This spill killed virtually all of the aquatic life in 40 miles of the river; from the site of the spill to where the river empties into the Shasta Reservoir. (Fechner-Levy 1991)

No phytotoxicity to crops as a result of Vapam fumigation was noted at Lawyer Nursery in 1998 or 1999. In the spring of 2000, a strawberry grower in Olympia treated a portion of his farm that is adjacent to the nursery with Vapam. This rotovate and roll application is a standard procedure for this grower and several days after the application I noticed some needle burn on approximately 100 *Pinus monticola* 2-1 transplants. This was in early spring prior to bud break and the cause of the needle necrosis was not readily apparent to me. This bed of transplants ran perpendicular to the neighbor's fumigation path and the end of the bed was within 50' of the

Vapam application. A significant number of trees at this end of the bed were affected and the concentration of affected crop declined in the bed as the distance from the fumigation increased. We sent samples of these affected trees to WSU Puyallup and they noted no pathogens or insects that could be attributed to causing the needle necrosis, so we concluded that *Pinus monticola* had some degree of sensitivity to Vapam. The percentage of the crop affected was insignificant and the trees broke bud and looked fine later in the growing season, so we did not give the matter much additional thought.

In the fall of 2000, I discussed the *Pinus* phytotoxicity incident of the previous spring with the fumigation contractor and because the areas that had been designated for fumigation were not near *Pinus* crops, we proceeded as we had the previous year. The application method utilized by the contractor was to inject a portion of the Vapam at a depth of 6-9" and spray a portion of the Vapam on the soil surface. Just behind the surface nozzles was a cultipacker which pushed a burm of soil over the treated surface soil, thus rolling the Vapam under the soil surface, and sealing the surface with the cultipacker. The label suggests that light watering or a tarp after rolling helps prevent gas escape. (AMVAC 1997) The Telone C-17 was injected at a greater depth with a separate tractor. We did not see any phytotoxicity in the nursery in 2000 following the Vapam fumigation.

In the fall of 2001, we did have some *Pinus monticola* transplants growing in close proximity to the areas we had designated for fumigation. We discussed this with the fumigation contractor and the decision was made to inject all of the Vapam at depths of 3 and 9 inches. Again, a cultipacker behind the application shanks sealed the soil.

The 2001 fumigation was done on September 26, 27, and 29. I was away from the nursery during the week following the fumigation application and when I returned to the nursery, I was advised by staff that a number of conifer crops adjacent to the fumigated areas were showing signs of distress. When I inspected the crops on October 8, 2001, I discovered that a significant number of *Pinus* and some *Picea* crops were exhibiting signs of Vapam injury. These symptoms are discolored needles that appear "bleached out". In some trees, only a portion of the needles showed this affect, and in

others, every needle on the tree was affected. In all, 13 species of *Pinus* and 6 species of *Picea* were affected. In some crops, only sporadic individual trees were affected and in other crops, as many as 90 percent of the population was affected. Of the damaged *Pinus* crops, 6 of 13 affected species suffered damage to over 40 percent of the population. The damage to *Picea* crops exceeded 4 percent in only 1 of the 6 species that were affected. Most of the damaged trees were within 50' of the fumigated areas, but one crop of *Pinus banksiana*, which sustained considerable damage, was over 400' from the source of the chemical.

It appeared that the MITC emerged from the soil and was held close to the soil surface either by an inversion or a very still air event. This type of condition is not uncommon during late September and early October in Olympia, as the days are generally warm with cool, calm nights. The unaffected portions of crops that suffered heavy damages were in areas such as the ends of beds, which were slightly elevated from the rest of the crop.

The Washington State Department of Agriculture investigated the incident to determine if the application was within the guidelines of the product label. The Department speculated that, "Some escape of fumigant is almost unpreventable unless the soil is tarped immediately after the application." The investigator also stated in the report, "I believe in this particular case, the applicator could have followed all the label directions and still caused the damage." (WSDA 2001) The Department concluded that the application was in compliance with the Vapam label.

Similar damage to *Pinus* crops as a result of metam sodium or dazomet have been reported previously on at least 4 occasions. In the fall of 1988, *Pinus monticola* seedlings were damaged at the J Herbert Stone Nursery in Central Point, Oregon as a result of fumigation with dazomet (Basamid) (Scholtes 1989) Dazomet is also considered a MITC generator, as the immediate breakdown product of dazomet is also methylisothiocyanate. (Landis, Campbell 1989) In this case, an untarped application of dazomet coupled with an inversion layer caused damage to non-target crop (*Pinus monticola*) seedlings. Unfortunately I did not read the published report of this incident until after the 2001 fumigation at Lawyer Nursery. More

recently, in November of 1999, an International Paper Nursery in Texas lost 20 million seedlings after fumigation with a mixture of Sectagon (metam sodium) and Chloropicrin. (Peoples 2001) A similar, but less severe incident, in terms of numbers of damaged seedlings, occurred at the Mississippi State Nursery, also in the fall of 1999. Another other crop injury incident involving metam sodium damage to *Pinus* seedlings occurred at the Arkansas State Nursery about 10 years ago. (Carey 2002)

CONCLUSION

The reported incidents of phytotoxicity to crop seedlings as a result of metam sodium or dazomet fumigation would indicate that certain conifer trees, particularly those of the genus *Pinus*, are very sensitive to MITC exposure. Based on our experience, *Pinus* foliage is significantly more sensitive to MITC than any of the other 300 species of woody trees that we grow. Of the more than 78,000 trees that were damaged at Lawyer Nursery, over 95 percent were pines. Had I researched Vapam prior to using this chemical in the nursery as thoroughly as I did to prepare this paper, I would probably have still used the material and been able to do so without damaging non target crop.

I think it is safe to speculate that while not all nursery managers read the entire nursery meeting proceedings every year, they do read the product labels for the pesticides they use. It is my feeling that the pesticide label is the most efficient place to publicize known risks to crop that may result from the application of a particular pesticide. Certainly there are risks of crop injury associated with many pesticides used by nursery growers. In the case of Vapam, there are a number of precautions that could be taken to minimize or eliminate the risk of crop injury. These would include not using the chemical within 400' of *Pinus* seedlings, and sealing the chemical in the soil more effectively with irrigation water or a tarp. It is my feeling that Vapam offers nursery growers an additional tool to reduce the impact of soil borne pathogens on bare root nursery crops. If known risk associated with use of this product, such as the documented sensitivity of *Pinus* seedlings, was identified on the product label, the effectiveness of this tool in the nursery would be much improved.

TABLE 1

SOIL PATHOGEN LEVELS DETECTED 10 MONTHS AFTER SOIL FUMIGATION

	<u>PHYTOPHTHORA</u>	<u>PYTHIUM</u>	<u>FUSARIUM</u>
	(PROPAGULES PER GRAM OF SOIL)		
FUMIGATED SOIL ACER RUBRUM 1-0	0	80 (VL)	880 (H)
UN-FUMIGATED SOIL ACER CIRCINATUM 1-0	0	410 (H)	2000 (VH)

(VL) = VERY LOW NUMBERS OF PROPAGULES OF THE PATHOGEN ISOLATED PER GRAM OF SOIL SAMPLE
(VL)= NUMBERS: (H) = HIGH NUMBERS: (VH) = VERY HIGH NUMBERS OF PROPAGULES ISOLATED

SOIL FUMIGATION 9-27-01 VAPAM/ TC17 PATHOGEN ASSAY 7-27-02 BY RIBEIRO PLANT LAB INC

SOIL SAMPLES WERE TAKEN FROM 1-0 SEEDBEDS

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Ken McNabb - citations

From: David South <southdb@auburn.edu>
To: <mcnabb@forestry.auburn.edu>
Date: 8/16/2002 3:56 PM
Subject: citations

dazomet reduces mycorrhiza

Recovery of growth potential of nursery stock produced on biocide-treated soils.

AU: Iyer, JG; Chesters, -G; Wilde, -SA
SO: 1969, Silva. fenn. 1969 3
(4), (226-33). [17 refs.].
PY: 1969
LA: English
LS: English, Finnish
AB:

Reports studies on nursery stock of: *Picea glauca* raised in soil treated with Mylone, and *Pinus radiata* and *P. resinosa* in soil treated with Vapam. Plants from treated plots were very succulent, had abnormally high shoot/root and height/diam. ratios, and very low sp. gr. and root surface area. Some fumigants impede mycorrhizal development and arrest P uptake. Recovery of balanced growth potential was achieved by application of $Al_2(SO_4)_3$ and/or fermented compost inoculated with mycorrhiza-forming fungi.

=====
Methyl bromide increases seedling production

=====
Effect of soil fumigation in the nursery on growth of Loblolly Pine seedlings and control of weeds.

AU: Hodges, CS
SO: 1960, Tree Plant.
Notes No. 42, 1960 (23-7). 12 refs.
PY: 1960
LA: English
AB: The

following treatments were tested: (1) MeBr (a) at 1 lb. / 150 sq. ft. (300 lb./acre) under a polythene cover, (b) vaporized and released at 300 lb./acre under polythene covers laid down by an automatic covering device, (c) as Brozone (50/50 MeBr and petroleum carrier) at 175 lb./acre injected into the soil and covered with polythene or left uncovered; (2) Vapam (a) at 50 and 100 gal./acre drenched into the soil with 1300 gal. water, or (b) at 50 gal./acre drenched into the soil and covered for 2 days with polythene. All treatments except (2a) gave increased seedling growth and reduced weeds, Brozone being regarded as particularly promising, since its application is highly mechanized (injected into the soil with chisel applicators and the soil then covered with polythene) and 6 acres/day can be treated vs. 1 acre by the standard method. Additional tests were made with a weedkiller, Eptam (ethyl di-n-propyl-thiolcarbamate) and a

Chemical Alternatives to Methyl Bromide¹

W. A. Carey²

Abstract—Three soil fumigants were evaluated at a nursery in Georgia and one in South Carolina. Seedbed density and seedling development were compared among plots treated with tarped and not tarped dazomet at 140 and 280 lbs/ac, tarped and not tarped chloropicrin at 125 and 250 lbs/ac, tarped MC33 at 350 lbs/ac and non-fumigated plots. Differences among treatments occurred only in South Carolina where both initial seedbed density and harvested seedlings differed with treatments. Among harvested seedlings, the high rate of dazomet and chloropicrin were not significantly different from MC33 but the low rates and controls were inferior. In a second study at the South Carolina nursery, dazomet (150 and 300 lbs/ac tarped and not tarped), MC33 (350 lbs/ac tarped), 1,3-D (290 lbs/ac tarped), metham-sodium (400 lbs/ac tarped and not tarped), dazomet (150 lbs/ac) plus chloropicrin (115 lbs/ac tarped), and metham-sodium plus chloropicrin (400 and 115 lbs/ac tarped) were evaluated with respect to weed control. MC33 and 1,3-D had the best herbicidal activity.

Keywords: Fumigation, *Pinus taeda*, seedling quality, weeds control.

INTRODUCTION

Methyl bromide (MBr) fumigation of soils controls a broad spectrum of fungi, nematodes, insects, and weeds (Thompson, 1991). Because all these taxa contain potentially destructive pests of forest tree seedlings, MBr fumigation, with 2% or 33% chloropicrin, has become almost universal in southern nurseries (South, 1992, Carey, 1991). Virtually all southern nurserymen fumigate and very few install control-plots

for evaluating pest problems (Carey and Kelley, 1993). Straightforward comparisons between fumigated and non-fumigated productions are rare. Comparisons to the pre-fumigation era are also complicated because the nursery industry itself has shifted most production to sandier soils during the time that fumigation has been extensively practiced (South and Davey, 1983). Handweeding cost provided adequate, reliable estimates for the economic benefits of MBr (South and

Gjerstad, 1980) and although alternative herbicides have reduced its importance for pine seedlings (South, 1992) the replacement in hardwood seedling production has been less effective (Stone, 1991). The sporadic occurrence (even in the absence of fumigation) of soil born insects and diseases further complicates estimates for the benefits of fumigation where non-fumigated comparisons are rare. Nevertheless, substantial savings are usually projected (South and Gjerstad, 1980) or

¹Carey, W.A. 1994. Chemical Alternatives to Methyl Bromide. IN: Landis, T.D.; Dumroese, R.K., tech. coords. National Proceedings, Forest and Conservation Nursery Associations. Gen. Tech. Rep. RM-257. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 4-11.

²Auburn University School of Forestry, 108 M. White Smith, Auburn, AL 36849-5418.

assumed (Stone, 1991) for MBr fumigation. In fact, forest tree nurseries had the largest projected benefit per acre or per pound of MBr used of all crops that utilized significant quantities (Anonymous, 1993).

In response to rumors of the regulatory disfavor of MBr, during the summer of 1992, the Auburn University Southern Forest Nursery Management Cooperative (AUSFNMC) planned small plot trials to evaluate alternative fumigants. With the first fumigation scheduled for the fall of 1992, the delusion of being ahead of the learning curve lasted only a few days. In November 1992 MBr was listed as a potential ozone depleter. Under the authority of the Clean Air Act, the EPA has now assigned a phase-out schedule with production termination for the year 2001. Before our first trials were finished we began to test additional fumigants and a few nurseries have now initiated production scale trials primarily comparing chloropicrin, dazomet or 1,3-dichloropropene with MBr. Like signs in store windows that count down the days to Christmas it seem only fair to warn nursery managers that there are only six more 1+0 crops before 2001.

ACKNOWLEDGEMENTS

Westvaco Corporation and International Forest Seed Com-

pany provided space and took care of all the non-fumigation practices required for the commercial production of pine seedlings at nurseries, respectively, in Summerville, SC and Statesboro, GA.. The cooperation of Hendrix & Dail, Inc. who provided the equipment and application expertise was critical to the study and the contribution of Basamid® (dazomet) by BASF and all other fumigants by Hendrix & Dail is gratefully acknowledged.

MATERIALS AND METHODS

Fumigation Treatments:

The fumigation treatments utilized these products; MC33 = MBC-33® (67% MBr + 33% chloropicrin), Triform® (70% 1,3 dichloropropenes + 30% chloropicrin), Dazomet is Basamid® (99% ai), Metham-sodium is

Sectagon-42® (42% ai), Chloropicrin is HDPic® (96.5% ai).

Table 1 lists the 11 fumigation treatments used on beds subsequently sown with pine seed. Each treatment was randomly assigned to positions within each of five blocks. The same relationship of treatments within blocks was used at both nurseries but at Statesboro a double-bed column contained each block and treatment plots were 68 ft long separated by 5 ft buffers. At Summerville blocks were at right angles to beds and each bed contained five 140 ft long treatment plots separated by 5 ft buffers.

At Statesboro, fumigation treatments were applied October 21 and 22, 1992 to nursery beds but not tractor paths (wheel ruts). Post-treatment soil samples were

Table 1. Fumigation treatments applied to loblolly pine production beds in Statesboro, GA and Summerville, SC.

Compound	Rate ¹	Application	Seal ²
None	None	None	Water
None	None	None	Plastic
Dazomet	140	Rototilled	Water
Dazomet	140	Rototilled	Plastic
Dazomet	280	Rototilled	Water
Dazomet	280	Rototilled	Plastic
Chloropicrin	125	Injected	Water
Chloropicrin	125	Injected	Plastic
Chloropicrin	250	Injected	Water
Chloropicrin	250	Injected	Plastic
MC33	350	Injected	Plastic

¹ Pounds per acre.

² Water seals are the irrigation equivalent of 0.25 inches of rain.

collected November 10, 1992 and March 5, 1993 before the treated bed structure was disturbed. The Summerville fumigation was March 18, 1993. Pre-treatment soil samples were collected and fumigation treatments applied after the field was disced but before beds were formed and both the bed and future tractor paths were treated.

Treatments for a second study, installed at Summerville in the fall of 1993, are listed in Table 2. The treatments were arranged at a randomized complete block with four blocks and plots were 12 ft by 110 ft and separated by 5 ft buffers. The area was disced and then fumigated, respectively, on October 14 and 26, 1993. Dazomet was rototilled into the soil in two six-foot-wide strips and the surface of all non-tarped plots was compacted ("power-rolled") using a drum roller. All other chemicals were injected and tarped in single 12-foot-wide strips.

Seedlings:

A single loblolly pine (*Pinus taeda*) half-sib seedlot was sown in each nursery on April 14 (27 days after fumigation) at Summerville and May 14 (201 days after fumigation) at Statesboro. Beds were stabilized with a synthetic resin at Summerville and with pinebark mulch at Statesboro.

Numbers of live seedlings (seedbed density) and dead seedlings (damping-off) were determined 35 days after sowing at both nurseries. Two one-foot-wide sections across nursery beds were delineated near the center of each of replicate plot and these were resampled throughout the study. Seedbed densities were determined again at both nurseries September 8-10, 1993 and January 2-5, 1994.

In January 1994, seedlings from the four center drills of each seedbed-density-plot were carefully removed from the soil and a random subsample of 25 of these seedlings was taken. Rootcollar diameters were used to determine numbers of culls (< 3.25 mm) and number one (> 4.76 mm) and number two (3.26 to 4.75 mm) seedlings per plot. Above and below ground portions of seedlings were separated

and each sub-sample was dried to a constant weight. Seedling parameters were calculated both on a mean seedling and a per square foot basis. Mean size and mass values for a 25 seedling replicate were multiplied by plot seedbed density to obtain area values. Seedling height was assessed only for Statesboro seedlings because Summerville seedlings were top-clipped (August 5 and September 16).

Weeds:

The second fumigation trial Summerville was placed in an area with a persistent infestation of nutsedge (*Cyperus* spp.), a weed not adequately controlled by alternative herbicides. Because this area was not put into seedling production, differences in weed control were assessed without the subsequent application of herbicides. Weed data only from this fumigation are

Table 2. Fumigation treatments applied to soil not subsequently used for seedling production (Summerville, SC).

	Chemical	Rate (lb/ac)	Application Method	Soil Seal
1	MC33	350	Injected	Tarped
2	Triform	290	Injected	Tarped
3	Dazomet	300	Rototilled	Tarped
4	Dazomet	300	Rototilled	Power-roll
5	Dazomet	150	Rototilled	Tarped
6	Dazomet	150	Rototilled	Power-roll
7	Metham-sodium	400	Injected	Tarped
8	Metham-sodium	400	Injected	Power-roll
9	Dazomet + Chloropicrin	150 115	Rototilled Injected	Tarped
10	Metham-sodium + Chloropicrin	400 115	Injected Injected	Tarped
11	Control	0	NA	NA

presented here. Percentages of ground covered by weeds for each treatment plot was estimated April 12 and all weeds within a randomly selected four-square-foot area near the center of each plot were counted May 10, 1994. Weeds were categorized as either "spring" or "summer" weeds and nutsedge (*Cyperus* spp.) was enumerated separately.

RESULTS

Seedling quality:

At Summerville, numbers of live seedlings differed significantly between fumigation treatments 35 days after sowing (Table 3). Subsequent mortality was negligible (0.4 seedling per foot) and seedbed densities in May strongly predicted those of September ($r=0.95$, $p=0.0001$) and January ($r=0.93$, $p=0.0001$). However, the effect of fumigation treatment was not significant in January ($p=0.30$).

At Statesboro, numbers of damped-off seedlings did not differ among fumigation treatments 35 days after sowing (Table 3). Although the mean seedlings per square foot in June decreased from 23 to 20.6 from June to January. Fumigation treatment effects (in contrast to the trend at Summerville) increased moderately over the same period (p for June = 0.15 and for January = 0.08). Correlations for June plot densities ($N=55$)

with those of September ($r=0.95$, $p=0.0001$) and January ($r=0.93$, $p=0.0001$) were significant.

Among dazomet treatments ($N=20$), seedling diameters in plots receiving 280 lbs/ac were larger ($p=0.03$) and there was more shoot ($p=0.0001$) and root ($p=0.009$) mass than at the 140 lbs/ac rate. Among chloropicrin treatments ($N=20$), seedlings in plots treated with 250 lbs/ac produced more root mass per seedling ($p=0.05$) and per square ft ($p=0.02$) than those treated with 125 lbs/ac. Tarping did not significantly effect seedling size or mass either in non-fumigated plots or those fumigated with dazomet or chloropicrin. Therefore, tarped and not-tarped treatments were combined for the analysis presented in Table 4. Among the five fumigation treatments (two rates each of chloropicrin and dazomet and one of MC33 and control), plots fumigated with MC33 or the high rates of chloropicrin or dazomet produced larger seedlings than those not fumigated or fumigated with low rates (Table 4).

Among dazomet or chloropicrin fumigations ($N=20$), no measured seedbed or seedling parameters differed either with rate of fumigant or tarping. Among non-fumigated plots ($N=10$), seedlings were taller ($p=0.02$) and had more stem mass ($p=0.02$) among non-tarped plots. However, seedbed density

and seedling root mass was not significantly larger among tarped compared to non-tarped plots. There were no significant differences among Statesboro seedlings in size or mass attributable to the five fumigant by rate treatments (Table 4).

Weeds:

Weed cover by plot and numbers of all weeds and of nutsedge per frame (4ft²) are presented in Table 5. In May, percentage weed cover differed ($p=0.0001$) between treatments. MC33 always had the fewest weeds and the 1,3-D and the metham-sodium plus chloropicrin were almost as good. These three treatments and the tarped metham-sodium and the dazomet plus chloropicrin were not significantly different.

In addition to nutsedge, pigweed (*Amaranthus* spp.), dogfennel (*Eupatorium capifillifolium*), and horseweed (*Coneza canadensis*) were common in the May survey and these (exclusive of nutsedge) were analyzed together as "summer-weeds". Other weeds were analyzed together as spring weeds. Summer weeds did not differ between treatments ($p=0.58$). Spring weeds differed significantly for treatment effects ($p=0.0001$) with the tarped dazomet treatments and the non-treated control having significantly more weeds than other treatments (Table 5).

Table 3. Seedlings per square foot by nursery, date, and treatment.

Summerville									
Chemical	Rate lbs/ac	May 93		Sept Jan 94					
		Tarp	Dead	Live	Live	Live	Ones ¹	Twos ¹	Culls ¹
MC33350	Yes	3.6	31.7	31.7	29.2	12.9	15.8	0.5	
Chloropicrin	250	No	8.6	27.2	28.3	28.3	9.3	15.5	3.5
Chloropicrin	250	Yes	4.4	30.1	30.2	30.2	9.3	18.8	2.0
Chloropicrin	125	No	3.6	29.1	30.7	30.7	11.3	16.6	2.7
Chloropicrin	125	Yes	2.8	30.1	28.6	28.6	11.4	14.8	2.3
Basamid	280	No	6.8	28.8	29.0	29.0	11.7	16.6	0.7
Basamid	280	Yes	7.2	30.6	27.4	27.4	13.8	12.5	1.1
Basamid	140	No	2.2	30.6	30.7	30.7	9.1	19.8	1.7
Basamid	140	Yes	3.0	30.2	30.5	30.5	8.3	21.3	0.9
None	0	No	11.8	27.8	27.4	28.1	6.4	19.6	2.1
None	0	Yes	5.8	29.2	29.1	28.0	6.9	19.3	1.8
Mean value			5.4	29.6	29.4	29.2	10.0	17.3	1.8
Isd for treatments ²			5.1	2.6	2.7	3.0	5.2	5.7	2.1
P for treatment effects ²			0.01	0.04	0.12	0.3	0.12	0.11	0.15

Statesboro									
Chemical	Rate lbs/ac	June 93		Sept Jan 94					
		Tarp	Dead	Live	Live	Live	Ones ¹	Twos ¹	Culls ¹
MC33	350	Yes	0.60	23.3	19.7	20.3	7.7	10.8	1.7
Chloropicrin	250	No	0.60	24.1	20.7	22.1	9.1	11.8	1.1
Chloropicrin	250	Yes	0.40	25.1	21.6	22.6	10.2	9.5	2.8
Chloropicrin	125	No	0.20	21.8	18.9	19.9	10.1	8.6	1.1
Chloropicrin	125	Yes	0.40	22.9	19.5	21.0	9.0	9.8	2.1
Basamid	280	No	0.60	23.6	19.7	20.7	7.3	11.7	1.6
Basamid	280	Yes	0.40	21.7	19.5	19.2	8.9	8.2	2.1
Basamid	140	No	0.40	21.5	18.2	18.6	8.1	8.9	1.6
Basamid	140	Yes	0.40	21.4	19.1	19.3	7.3	9.1	2.9
None	0	No	1.20	23.6	20.0	20.8	8.2	10.2	2.3
None	0	Yes	0.00	23.9	20.7	21.5	8.3	10.4	2.7
Mean value			0.47	23.0	19.7	20.6	8.6	9.9	2.0
Isd for treatments ²			1.02	2.81	2.19	2.59	3.16	3.0	1.88
P for treatment effect ²			0.70	0.15	0.06	0.08	0.61	0.25	0.49

¹ Seedling rating where *ones*, *two* and *culls* have ground line diameters, respectively of 4.76 mm, 4.75 mm - 3.26 mm, and 3.25 mm.

² Statistics from SAS ANOVA.1

DISCUSSION

The herbicidal activities of the fumigants was assessed within seedbeds but standard herbicide applications controlled weeds to the extent that production was not effected. Non-soil associated disease and insect problems were likewise expected to be controlled by standard practices. We expected that any important differences between fumigants would be measured for seed efficiency and seedling quality

due to soil-pests other than weeds. The economic aspects of seed efficiency (that is, the number of plantable seedlings culls omitted produced per unit of pure live seed) have been addressed by South (1987) who showed that small changes had significant economic impacts.

Non-significant differences between tarped and not tarped applications of dazomet or chloropicrin were somewhat

surprising. Plastic tarps increase effective concentrations of MC2 or MC33 (Munnecke and Van Gundy, 1979). However, MBr boils at 4.6°C and is more physically active than most other fumigants at normal soil temperatures. Dazomet, applied as a granular product evolves its fumigant in contact with soil moisture. Our estimates for soil fungi (data not presented) indicate that much of its activity can occur after tarps would normally

Table 4. Seedbed densities and seedling size and mass by fumigant rate and nursery.

Summerville (271 days after sowing).					
Fumigant	Rate (lbs/ac)	Seedlings (/ ft ²)	Diameter (mm)	Shoot (gm OD)	Root (gm OD)
MC33	350	29.2 a ¹	4.70 a	2.45 ab	0.78 a
Chloropicrin	250	29.6 a	4.56 abc	2.38 ab	0.76 ab
Chloropicrin	125	29.2 a	4.40 cd	2.22 bc	0.67 b
Basamid	280	28.2 a	4.68 ab	2.57 a	0.82 a
Basamid	140	30.6 a	4.44 cd	2.00 c	0.69 b
None	0	28.1 a	4.21 d	2.00 c	0.68 b
Mean value		29.1	4.48	2.26	0.73
Isd for treatments ²		2.3	0.23	0.28	0.08
P for treatment effect		0.19	0.001	0.001	0.001
Statesboro (250 days after sowing).					
Fumigant	Rate (lbs/ac)	Seedlings (/ ft ²)	Diameter (mm)	Shoot (gm OD)	Root (gm OD)
MC33	350	20.32 abc	4.52 a	3.31 a	0.93 a
Chlorpicrin	250	22.37 a	4.63 a	3.40 a	1.00 a
Chlorpicrin	125	20.47 abc	4.71 a	3.40 a	1.05 a
Basamid	280	19.95 bc	4.60 a	3.37 a	1.02 a
Basamid	140	18.99 c	4.53 a	3.22 a	0.97 a
None	0	21.16 ab	4.47 a	2.86 a	0.94 a
Mean value		20.6	4.58	3.25	0.99
Isd for treatments		1.93	0.28	0.52	0.15
P for treatment effect		0.012	0.52	0.21	0.61

¹ Means followed by the same letter not significantly different (alpha = .05).

² "Isd" and "P" values from SAS GLM.

Table 5. Weeds by fumigant and date on ground not cultivated after a fall fumigation.

Fumigant	Rate lb/ac	Chl. lb/ac	Tarp	Cover % ¹ (May)	Numbers ² (April)	Nutsedge ² #s
MBr	235	115	Yes	29 c	8.5 c	0.25 c
1,3-D	290	0	Yes	35 c	14.5 c	2.00 c
Dazomet	300	0	Yes	95 a	101.5 a	36.70 abc
Dazomet	300	0	No	65 b	79.3 ab	63.52 a
Dazomet	150	0	Yes	95 a	82.8 ab	29.75 abc
Dazomet	150	0	No	70 b	81.8 ab	56.75 a
Dazomet	150	115	Yes	46 c	55.0 abc	47.25 abc
Metham-sodium	400	0	Yes	36 c	28.5 c	10.25 bc
Metham-sodium	400	0	No	90 a	35.2 bc	5.75 abc
Metham-sodium	400	115	Yes	38 c	17.3 c	5.50 bc
Control	0	0	No	100 a	91.8 a	31.75 abc
Isd				16.22	44.21	38.22

¹ Percentage of ground covered by weeds on Apr. 12, 1994.

² Number of weeds in four square foot frame on May 10, 1994.

be removed. Chloropicrin is liquid at normal soil temperatures which evaporates slowly (boiling point 112°C) to produce a gas heavier than air. It seems possible that chloropicrin evaporated and subsequently diffused slowly enough without tarping to achieve a large percentage of that effective concentration produced under plastic. Differences between effective concentration of the high and low rates of dazomet or chloropicrin indicate that measured variables (seedling and fungi but not weeds) were sensitive to treatment differences.

Seedling sizes and masses differed between fumigation treatments only at Summerville where all differences followed the same pattern. Seedlings did not differ significantly between the MC33 or the high rate of

chloropicrin or dazomet but these were significantly larger than seedlings from plots treated with the low rates which did not differ from non-fumigated controls. Final seedbed densities did not differ among treatments but sizes and masses were negatively correlated with plot densities.

The effects of seedbed density on loblolly pine are well documented (South, *et al.* 1990). Density differences at the two nurseries result largely from sowing rates and complicate inferences for fumigation treatment effects. At Summerville, the 30 seedlings/ft² at the first survey changed negligibly before harvest but at Statesboro, the initial 23/ft², was to 20/ft² during that period due to causes not ($p = 0.14$) associated with fumigation treatments. Differ-

ences in seedbed densities, between treatments, increased but remained non-significant at Statesboro and decreased at Summerville.

Non-significant differences for seedling growth among treatments at the Statesboro nursery could be attributable either to environmental conditions unfavorable for diseases controlled by fumigation or just the chance "escape" of the study area from a normally sporadic pathogen development.

Not surprisingly, estimates of weed cover in April and numbers of weeds per sample plot in May indicate essentially the same relative herbicidal activities for the fumigant treatments. It seems unfortunate that MC33, which will soon be unavailable, was the best fumigant tested but

1,3-D was almost as good. Although increasing the concentration of chloropicrin usually decrease the herbicidal activity of MBr, it significantly (in April) enhanced the activity of dazomet and insignificantly that of Metham-sodium. Dazomet had the least herbicidal activity of the fumigants.

Nutsedge is currently one of the most difficult weeds to control in southern pine nurseries. Although plants per treatment are presented in Table 3. with a multiple means comparison (Duncan's for SAS ANOVA) it's logical to believe that tuber producing plants will not (as required by these statistics) be normally distributed. Nutsedge plants differed significantly between treatments for non-parametric statistics also (SAS NPAR1WAY) but multiple comparisons are difficult. Anyway, no treatments were significantly different from the control.

As a part of these studies that will be presented later, soil samples were collected each time seedlings were surveyed and subsequently plated on media selective for the development of *Fusarium* (Nash and Snyder, 1961), *Rhizoctonia* (L. J. Herr, 1973) and *Trichoderma* (Elad et al, 1981). Numbers of fungi identified on selective media did not differ significantly among blocks or rows for pre-treatment soil samples but all

fumigation treatments significantly reduced populations. The assessed fungal "groups" were differentially affected by fumigants and subsequently recovered to prefumigation levels at different rates.

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AUBURN UNIVERSITY
SOUTHERN FOREST NURSERY MANAGEMENT COOPERATIVE

RESEARCH NOTE 95-1

Testing Alternatives to Methyl Bromide Fumigation at New Kent Nursery

by

Bill Carey

INTRODUCTION:

The improved seed efficiency and seedling quality attributable to methyl bromide (MBr) fumigation has appeared to be independent of region, soil type, or tree species (Carey, 1994). Unfortunately, recent trials indicate that efficiencies of potential replacements for MBr will be more site specific. This makes preliminary screenings advisable at each nursery.

The effects of four soil fumigants on seed efficiency and seedling development of loblolly pine and on the abundance of selected soil fungi were evaluated at the New Kent nursery in Virginia. Non-fumigated plots were compared with plots fumigated with chloropicrin, MC33 or 1,3-dichloropropene plus chloropicrin. Dazomet treated beds were compared with non-fumigated beds in a non-replicated trial. Seedlings from the replicated study did not differ among fumigants for seedbed density or root or shoot weights. Numbers of colonies of *Fusarium* but not *Trichoderma* isolated from soil differed significantly 35 and 243 days after fumigation.

METHODOLOGY:

Fumigation Treatments:

Three fumigation treatments were compared:

- | | |
|----------|---|
| MC 33 | (350 lbs/ac 67% methyl bromide plus 33% chloropicrin) |
| Triform® | (300 lbs/ac 70% 1,3 dichloropropenes plus 30% chloropicrin) |
| HDPic® | (300 lbs/ac chloropicrin at 96.5% ai). |
| Basamid® | (275 lbs/ac dazomet at 99% ai) |

Each was applied to plots nine beds wide (60 ft) by 500 feet long (see Figure 1). Fumigants were injected into the soil April 14, 1994 and covered immediately by plastic tarp. The Basamid® was applied April 19 and immediately rototilled into freshly irrigated soil but not tarped.

Seedlings:

A mixed lot of loblolly pine seed collected 1993 was sown in all study plots. All plots except those treated with dazomet were sown May 3, 1994 (18 days after fumigation). The dazomet treated beds were sown May 10 (21 days post treatment) when lettuce seed

sown in those beds May 2 to test residual phytotoxicity had germinated and appeared healthy.

Seedlings within two-square-feet were counted at four systematically located points within the fumigated portion and four points within the not fumigated portion of each treatment plot. Seedlings were counted 43 and 243 days after sowing (June 15 and December 12, 1994). When the December counts were made, more than 25 seedlings were removed from each counted subplot for determination of size and mass.

Soil Fungi:

Soil samples were collected from each replicate plot two days before fumigation (4/12/94) and during seedbed density counts. Soil-agar suspensions were prepared from the soil samples and placed on petri dishes of media selective for *Fusarium*, *Trichoderma*, and *Rhizoctonia*. Fungal colonies (colony forming units—CFUs) were counted in each dish after incubation for one week.

RESULTS:

Differences in seedbed densities were not significant among replicated treatments and controls (Table 1). This could be attributable to environmental conditions unfavorable for diseases controlled by fumigation or just the chance "escape" of the study area from sporadic pest problems. The recent fumigation history undoubtedly reduces probable response range for the 1994 fumigation treatments. The suppression of chronic, soil born, diseases by MBr for more than two years is strongly indicated by past studies. Nevertheless, two more plantable seedling per square foot, among MC33 and Triform® treatments would increase production by about 60,000 seedlings per acre.

Trichoderma increased soon after fumigation with MC33, chloropicrin or Triform® at New Kent and this has occurred at other nurseries as has a slower rebound after dazomet treatment. The reduction in cfu's isolated on Herr's medium indicates that the dosage of Triform® was effective for many species but the decrease in *Fusarium* was non-significant 35 days after Triform® fumigation. This is difficult to understand. *Fusarium* has not been hard to control in the past. *Fusarium* control by Triform® needs careful evaluation. Although all genera were suppressed among the first post-treatment samples numbers rebounded for December samples and were not significantly different from not treated soils.

No statistical confidence can be attributed to any discussion for the dazomet treatment. Effects could be due to the unique plot location or sampling error and not the fumigant. Nevertheless, the dazomet treated plot performed poorly compared to the simultaneously sown control plot. A seven seedling per square foot decline in seedbed density between May and December, that did not occur in the adjoining control cannot be explained by collected data. December mean seedbed densities and the lsd of 3.8 seedlings/ft² applicable to the replicated treatments indicate no similar declines among those 12 plots. A (unlikely but possible) localized, post emergent damping-off due to disease or chemical, residual, phytotoxicity could cause the reduced bed density. Six fewer plantable seedlings than control beds per square foot (9 compared to Triform® of MC33) could reduce per acre production by about 172,000 seedlings. Dazomet should not be considered for this nursery before additional trials prove that a rare, or controllable, event occurred in 1994.

MANAGEMENT IMPLICATIONS:

Basamid® should not be used without testing at the specific nursery using large plot trials to compare alternatives. Triform® and chloropicrin continue to look promising as eventual substitutes for Methyl-bromide.

Table 1. Seedling data by fumigation treatment and sowing date.

Fumigant	Date Sow	Number/ft ²		Dia.	Seedling Grade*			Weight**	
		5/15	12/12		1's	culls	1's+2's	total	root
None	5/3	29.6	31.1	3.8 a	1.7 a	4.4 a	26.7	71.7	18.0
MC33	5/3	31.2	30.9	4.0 ab	3.4 ab	2.1 ab	28.7	77.5	18.3
Triform®	5/3	29.6	30.6	4.2 b	4.9 ab	1.6 b	29.0	85.5	19.6
HDPic	5/3	30.0	30.0	4.2 b	5.8 b	2.4 ab	27.6	79.8	18.9
	lsd ⁺	3.0	3.8	0.3	3.1	2.5	4.9	20.0	3.3
None	5/10	28.8	31.6	3.8	1.2	5.2	26.4	81.2	18.2
Dazomet	5/10	29.0	22.5	4.1	3.7	2.3	20.1	62.9	14.7

* Seedling grades of 1's, culls and 1's+2's, respectively, refer to root collar diameters > 4.75mm, < 3.2mm, and > 3.2mm. The numbers reported for grade and for weight are for square foot of bed.

** Weight in grams per ft² of nursery bed.

+ lsd is for SAS ANOVA and refers only to the 5/3 sowing date.



Auburn University Southern Forest Nursery Management Cooperative

TECHNICAL NOTE 96-2

THE LOSS OF METHYL BROMIDE AS A FUMIGANT IN FOREST TREE NURSERIES AND THE IMPACT ON REFORESTATION PROGRAMS

by

Bill Carey and Ken Mc Nabb

INTRODUCTION

Methyl bromide (MBr) is currently used as a soil fumigant in most southern forest tree nurseries. Over the past 40 years MBr has proven to be a consistently reliable pesticide that enhances seedling production and suppresses soil-borne pests. It has become the industry standard and is an essential component of virtually every pest management program in southern forest tree nurseries. By reducing populations of many pests, the use of MBr can reduce the demand for more specific pesticides such as herbicides, fungicides, and insecticides. Moreover, MBr typically results in superior seedling growth. There is little doubt that MBr is one of the most important pesticides used in the production of forest tree seedlings in the southern U.S.

The U.S. Environmental Protection Agency has ordered a complete ban on the production of MBr after January 1, 2001 and production is currently frozen at 1991 levels. Legal jurisdiction for this ban falls under the Clean Air Act which the EPA administers. This act addresses chemicals suspected of depleting stratospheric ozone. A consensus has emerged in the scientific literature during the last 20 years that the concentration of stratospheric ozone was declining and that chlorinated fluorocarbons (CFC's) were the cause. To address this, the Montreal Protocol on substances that deplete the ozone layer was signed by several nations in 1987 to bring about the eventual phase-out of CFC's. Little attention was given to bromine until 1991 when its class of chemicals was added to a growing list of potential ozone depleters. MBr is 84% bromine by weight and is considered by the EPA to be a significant contributor to ozone depletion. Even though Montreal Protocol signees decided in 1992 that the MBr issue should be reconsidered in

1995 after a technical options assessment, MBr was already (in 1992) scheduled for termination in the U. S. Lawsuits brought by several environmental groups had triggered an automatic phaseout of MBr under the Clean Air Act. The Montreal Protocol, but not the Clean Air Act has allowances for economic and scientific uncertainty.

Nursery managers and pest specialists are very concerned about the probable loss of this important pesticide. This Technical Note reviews the current status of MBr use in forest tree nurseries, its effects on seedling production, and the most probable alternative fumigants. We hope to provide a basis for further rational discussion regarding the potential loss of MBr and subsequent effects on forest tree seedling production in the South.

MBR USE IN SOUTHERN NURSERIES

Application Frequency and Rates

Approximately 96% of southern nurseries use soil fumigation and 90% of the fumigant used is MBr (Jang et al. 1993). MBr is most commonly applied in southern nurseries once every four years prior to two years of pine seedling production followed by two years of cover crop. Fumigation is usually applied in the fall or spring preceeding the first pine crop in the rotation. The gas is injected into the soil and immediately covered with a continuously overlapping plastic tarp.

The total amount of MBr used in southern forest nurseries is estimated at 161,000 pounds. This is about 0.33% of the estimated 49 million pounds used for soil fumigation in the U.S. in 1990 (U.S.D.A. 1994). Amounts of MBr used to produce seedlings vary between individual nurseries based on rotation schemes, seedbed densities, and formulation (Table 1). The standard application rates are either 350 lbs/ac of 98% MBr (MC2) or 400 lbs/ac of 66% MBr (MC33) (South and Zwolinski 1996). Using these rates, the bromine applied would be 330 lbs/ac for MC2 formulations and 194 lbs/ac for MC33 formulations. There is, therefore, the potential for

TABLE 1. Bromine requirements for the annual production of 20 million seedlings using MC2 or MC33 for two fumigation schedules and at two seed bed densities.

<u>Crops/Treatment</u>	<u>Seedlings/ft²</u>	<u>Acres Treated</u>	<u>Bromine in Tons</u>	
			<u>MC2^b</u>	<u>MC33</u>
1	15	46	6.60	5.04
1	25	27.5	3.96	3.01
2 ^a	15	23	3.31	2.52
2	25	13.75	1.98	1.51

(a) two years of pine production followed by two years of cover crop

(b) MC2 is 350 lb/ac 98% MBr and 2% chloropicrin, MC33 is 400 lb/ac 66% MBr, and 33% chloropicrin

considerable variability in the amount of bromine used per unit of production between nurseries. Just over the range of schedules considered in Table 1, bromine requirements varied from 1.5 to 6.6 tons per year for the production of 20 million seedlings.

Efficacy for Soil-Borne Pest Control

MBr is used to control weed seed, soil-born fungi, nematodes, and insects. Formulations with 2% chloropicrin are suggested when perennial weeds and nematodes are the primary pest problem, and those with 33% chloropicrin are indicated when more difficult-to-kill fungi are the pest target (South and Zwolinski 1996, May 1985). MBr fumigants were instrumental in greatly reducing the impact of difficult-to-control soil fungi such as the charcoal root rot pathogen (*Macrophomina phaseolina*) at some nurseries (Seymour and Cordell 1979). MBr fumigation has been superior to soil drenches containing fungicides for the control of *Fusarium* spp. in nurseries (Rowan 1981).

MBr containing fumigants help control perennial weeds, such as nutsedge (*Cyperus* spp.), which currently registered preemergent herbicides seldom adequately control. Postemergent nutsedge control is limited because of the lack of herbicide selectivity. The use of MBr for weed control in hardwood seedbeds may even be more critical because of the lack of suitable pre- or post-emergent herbicides (South 1994). Nursery managers will therefore often fumigate immediately prior to every hardwood seedling crop to reduce the amount of hand weeding that otherwise would be required.

THE EFFECTS OF MBR ON SEEDLING PRODUCTION AND QUALITY

The extensive use of MBr in forest tree nurseries across the South (Jang *et al.* 1993) is our best indication of its consistent effectiveness across a wide range of conditions. Moreover, increases in both size and numbers of seedlings after fumigation are abundantly documented in studies carried out in forest tree nurseries over the last 40 years. Table 2 summarizes the results of 40 years of research regarding the effect of MBr on seedling numbers and size. Most of the currently available fumigants were tested between the late 1940's and 60's. After the superiority of MBr was established, little additional research occurred until the loss of MBr's registration became likely. Only 6 of the 33 reports included in Table 2 are less than 20 years old. Most data applies to pines or spruces. For these comparisons, not fumigated beds produced 33% fewer seedlings than those fumigated with MBr or MC33. Not fumigated beds contained 27% fewer seedlings than Metham-sodium (SMDC) treatments which were the second best in average performance of the widely tested fumigants. Based on average performances, where MBr fumigated beds produced 100 seedlings, controls would be expected to produce 67 seedlings (that is 100 - 33%). Using a South-wide production figure of 904 million seedlings (Moulton *et al.* 1995), Methyl bromide could theoretically be responsible for 33% of this production, or 298 million seedlings. Calculating at \$30/1000 seedlings, the value of this production increase is 8.9 million dollars annually,

TABLE 2. Effects of fumigation on numbers and sizes of plantable forest tree seedlings as the average percent reduction in not treated compared to treated nursery beds.
(From Carey, 1994a)

<u>Chemical</u>	<u>% Reduction from the Controls (# comparisons)</u>		
	<u>Seedling Numbers</u>	<u>Seedling Size</u>	<u>N*W^a</u>
Mbr	33 (99)	14 (36)	41
MC33	33 (58)	1 (20)	28
Metham Sodium	27 (58)	5 (26)	5
Ethylene Dibromide	22 (17)	-2 (12)	27
Dazomet	15 (48)	2 (28)	17
Formaldehyde	14 (5)	14 (4)	27
Chloropicrin	14 (13)	22 (12)	36
DD	6 (27)	6 (4)	3
Mean (sum)	25 (345)	25 (142)	2

^aDifference in products of seedling weight and number for treatment minus that for control as a percent of treatment.

Not only has MBr increased the average number of seedlings produced per unit area of nursery bed, it has also increased the average size of those seedlings. A review of 36 published comparisons conducted over the past 40 years in which some aspect of seedling size was compared between seedlings from not fumigated and MBr treated beds (Table 2), found that seedlings from the MBr treated beds averaged 14% larger (Carey 1994a). The effect of bed density on seedling size was not addressed in the original reports but logical inferences can be made. If fumigation effected the number of seedlings without enhancing the growth of individual seedlings, then as bed density increased mean seedling size would decrease. Among the studies averaged in Table 2, this occurred only for ethylene dibromide (EDB) treatment and seedlings were both larger and more numerous for other fumigation treatments and this growth enhancement was greatest for MBr treatments. In Table 2, the variable N*W is a dimensionless number. Within each study, N*W is the product of seedbed density and either average biomass (if reported) or diameter for not treated beds compared to that for fumigated beds. In Table 2, the number presented for N*W is the average for the number of comparisons for seedling size.

NON-TARGET EFFECTS OF MBR USE

Effect on Non-Target Soil Microorganisms

There is a general conception that MBr is universally toxic to all organisms and that fumigated soils are left essentially sterile. This is not true and populations of soil fungi after fumigation are well documented (Munnecke *et al.* 1978, Wensley 1953). For example, *Trichoderma* has been shown to be resistant to MBr. This highly competitive soil fungus suppresses several pathogenic fungi (Strashnow *et al.* 1985, Danielson and Davey 1969, Wensley 1953). In AUSFNMC trials through the South (Carey 1996, 1995b) *Trichoderma* has consistently increased after treatments

with MBr or chloropicrin but decreased after some other treatments. A. L. Foster (1961) concluded 35 years ago that "MBr may well be as important for what it leaves in the soil as for what it removes." It is unfortunate, and surprising, that differences in the "selectivity" of MBr among microbes is known with little more precision today than in 1961.

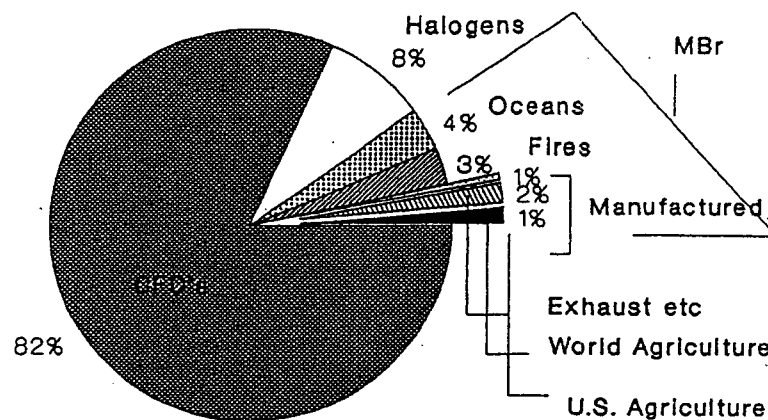
Human Health

MBr is a toxic substance that when used on the scale required to fumigate a forest tree nursery is probably best left to professionals. Although exposure is most likely to come thorough inhalation, dermal contact can also cause serious, systemic symptoms. Although not as acutely toxic as some other currently used fumigants MBr would be more hazardous were it used in pure form (as in some structural fumigation) due to its lack of color and odor. The MBr formulations used in nursery soil fumigations are mixed with chloropicrin, a potent lacrimator and the active ingredient in tear gas, which provides an effective early warning signal of exposure. *Toxicity* refers to the inherent poisonous potency of a compound, and *Hazard* refers to the risk or danger of poisoning when a compound is used or applied (Ware 1978). A one-hour exposure to MBr at 2,000 ppm can be lethal (Thompson 1992). That is the equivalent of a one-pound can of MBr dispersed in 2,000 ft³ of air or roughly a large bedroom (15 ft by 15 ft). Carbon tetrachloride, once common in chemistry labs and dry-cleaning shops, could be lethal at 300 ppm, and EDB at 200 ppm (Thompson 1992). Chloropicrin is about 1,000 times more toxic than MBr, yet Army personnel are regularly exposed to it during training. Chloropicrin can be lethal to mammals at an exposure of 8 ppm for only 10 minutes. This is one pound dispersed in a 290,000 ft³ or a 6.5 ft high room the size of a football field. Nevertheless, because nobody voluntarily breaths even very dilute concentrations of tear gas (as little as 1 ppm is intolerable), the more *toxic* chloropicrin added to the odorless MBr reduces the *hazard*.

Ragsdale and Wheeler (1995) provide a good summary of the long term effects of exposure to Mbr. They found little evidence for chronic (or cumulative) effects in laboratory animals. In long term studies, no cancers were detected in rats exposed by inhalation to various concentrations for 5 days/week for 6 hr/day for 29 months. Neither did rats fed food treated with MBr (up to 500 ppm Br) develop cancers or have reduced reproductive performance or increased birth defects. These are very reassuring statistics and even more remarkable when compared to some of the other more commonly used agricultural pesticides. In the final analysis the authors concluded that MBr can be safely used when label precautions are followed.

Ozone Depletion

Measurable and historic reductions in stratospheric ozone (O₃) are believed to have occurred and to be occurring due to human-made chemicals. Stratospheric ozone absorbs ultraviolet (UV) light especially wavelengths around 280 nm (UVB). UVB is biologically active, it can kill microorganism, causes skin to sunburn and tan, and exposure correlates with increases in skin cancer. Therefore, reduced ozone could increase UVB and cause reductions in global biological productivity and increases in human skin cancer. Current science supports the idea that certain chemicals deplete stratospheric O₃. The bromine from MBr is one of the chemicals that is believed to contribute to this change. Much of the inorganic Br in the stratosphere (about 46%) is from halons (Br containing CFC's) and since some halons persist for 40 years the annual flux to



Estimated from abundance X activity.

Figure 1. Stratospheric Ozone Depletors (chlorinated and brominated only)

Figure 1 summarizes some general estimates (abundance x activity) for the contributions of the major components to ozone depletion. Most of these are from a 1994 article by R. J. Cicerone. About half the organic Br in the stratosphere is probably from halon and most of the rest is from MBr of which about 20% is thought to be manufactured. Although Br is less than 1% as abundant as Cl in the stratosphere it is thought to be 40 times (+ or - 50%) more destructive per atom. Therefore, about 18% of O₃ destruction (assuming incorrectly that all is from either Br or Cl) would be by Br with the 20% of Br from manufactured MBr causing about 5.6% of O₃ destruction. About one third of manufactured MBr is from soil fumigation. The Figure 1 projection of 4% for anthropogenic MBr is less, but not much less than the estimate from UNEP, 1992 of from 5 to 10%.

the stratosphere is roughly the same as production, which in 1990 was about 7.2 million Kg (Cicerone 1994). Estimates for the actual percentage of ozone decline are controversial. In fact, a minority of scientists, including S. Singer developer of the ozone-sensing instrument flown on satellites, believe there is insufficient evidence to indicate any decrease (Monastersky 1995).

The contributions of what are currently thought to be the significant ozone depletors are represented in Figure 1. These estimates were generated by trying to reach a balance between estimates from the papers cited throughout this paragraph. However, estimates in atmospheric chemistry frequently include large margins for error and different pictures can be generated. Nevertheless, the contribution of MBr used in agriculture can be seen to be a small part of the picture. Unlike the CFC's, which are all human-made, there are significant natural sources and sinks of MBr (Butler 1994). It is estimated that the atmospheric concentration of MBr is between 9-13 pptv (parts per trillion volume) which indicates a total quantity of 1.5 to 2.1×10^8 kg. Approximations based on what are thought to be major sources are (in millions of kg) oceans 35, fires 30, motor vehicles 15, and MBr manufactured for pesticides etc 30. There are significant problems with calculating these numbers. These and most other estimates include a margin of error of about 50%. Secondly, the estimated magnitudes of MBr sources have changed considerably during the last two years. For example, the magnitude of fire (used largely to clear land for agriculture) as a source was only recently discovered (Mano and Andreae, 1994) as was the potential for the oceans to function potentially as both a source and a sink for MBr possibly compensating for changes in other sources (Butler 1994). Also, it has only recently been determined that under many soil conditions, 50% or less of MBr applied during fumigation "escapes" to the atmosphere (Gan *et al.* 1995, Yates *et al.* 1995). The atmospheric residence time of MBr was estimated to be close to two years in 1993 (Mano and Andreae, 1994) but recently has been estimated to be as short as nine months (Adler 1995). Obviously, our understanding of ozone depletion and the relative contributions of human and natural influences on ozone flux is far from satisfactory.

AN EVALUATION OF MBR SUBSTITUTES

Four of the currently available soil fumigants that we listed in Table 3 (MBr, chloropicrin, 1,3-dichloropene, and dazomet) these, plus metham sodium and the several combinations of these five chemicals are our most probable choices for replacements that will be available by the year 2001. Although methyl iodide seems potentially to be an effective replacement and has worked well in trials (Ohr *et al.* 1996, Sims *et al.* 1995) it still needs a sponsor who will pay for the environmental and toxicological studies needed for registration. Each of the four currently available MBr substitutes has its own physical characteristics, application methodologies, and effect on seedling culture.

Fumigant efficacy depends on uniform distribution through the soil and toxicity to soil organisms, both pathogenic and beneficial organisms. Soil characteristics at fumigation such as moisture and organic matter content, can alter the distribution of fumigants through the profile (Munnecke and Van Gundy 1979) as well as the sensitivity of soil microorganisms to exposure

TABLE 3. Properties of Fumigants (from Munnecke and Van Gundy 1979)

	Fumigant			
	<u>MB</u>	<u>Chloropicrin</u>	<u>1,3 dicloro-propene</u>	<u>Dazomet</u>
Molecular Weight	95.0	154.0	112.0	--
Vapor Pressure (mm Hg @ 20°C)	1,380.0	20.0	21.0	21
Boiling point (C°)	4.6	112.0	104.0	--
Solubility in H ₂ O (% @20°C)	1.6	0.2	0.3	0.76

(Danielson and Davey 1969, Wensley 1953). The better the diffusion of a fumigant through both the air and the water fractions of a soil the more homogenous will be concentrations through the profile. The superior physical characteristics of MBr, especially with respect to vapor pressure (the gas pressure when at equilibrium with the liquid phase) and solubility in water as compared to some alternative fumigants for its distribution throughout a soil profile, should be apparent from Table 3.

Data from more recent studies are summarized in Table 4 which is limited to 1993 and 1994 trials carried out by the AUSFNMC. Together, the data in Tables 2 and 4 provide our best estimates for the efficacy of different fumigation treatments within forest tree nurseries. Changes in cultural practices have undoubtedly modified the impacts of fumigation since most of the data in Table 2 were collected. Considering recent trials only (Table 4), seedling numbers have differed negligibly between treatments and controls. However, these trials did not occur in nurseries with the severe soil-borne disease problems that were common during early fumigation studies and since MBr has done much to reduce the population of soil-borne pests at most nurseries its effects cannot be entirely removed from these trials. Differences may be smaller than they would have been in nurseries not previously treated with MBr. The effects of fumigation on seedling size have been similar among the older studies presented in Table 2 and among the more recent studies in Table 4. Significant increases in seedlings size have occurred in this instance without a change in bed density.

Solarization

Solarization is a treatment often mentioned as a possible substitute for MBr. By covering the ground with plastic tarps, soil temperatures can sometimes be raised high enough to kill some species of pathogenic fungi, nematodes and insects. This technique has been used for soil treatment in vegetable production. In forest tree nurseries, however, its potential utility is limited. To reach temperatures lethal to target pests, the plastic must be placed over clean soil, preferably well tilled, and not too dry, during several weeks in the summer. Since our nurseries are sown in the early to mid spring to avoid the negative effects of high soil temperatures on germination and seedling establishment this would require solarization to be done the previous summer. Either the

TABLE 4. Average percent reduction in numbers and weights of conifer seedlings among control beds by fumigation treatment for trials in 1993 and 1994. (From Carey 1995a)

<u>Chemical</u>	<u>Percent reduction among controls</u>			<u>N*W^a</u>
	<u>No. Of Studies</u>	<u>Seedling Numbers</u>	<u>Seedling Weight</u>	
MC33	5	0	17	17
Metham Sodium	2	4	6	10
Dazomet	6	-6	12	3
Chloropicrin	7	0	18	17
Triform	3	0	21	21
<u>Mean</u>		-2	16	13

^aDifference in products of seedling weights and numbers for treatment minus that for control as a percent of treatment.

plastic would have to be maintained for several months or the ground would be exposed to the forces of erosion for a long period of time. Either way, the land would have to remain fallow. Large-scale field solarization will invariably have irregular effectiveness due to wet spots and soil texture influences. Although it may not be difficult to raise mean surface temperatures to near 50°C, at a depth of 6 to 10 inches temperatures will be 15-2° cooler.

Organic Amendments

The possibility of using organic amendments to manage populations of soil microorganisms so that pathogens are held in check by natural processes has long been a research ambition of plant pathologists. Interests in that area of research has increased and abated for several decades as positive laboratory results failed to be duplicated in the field and the mechanisms responsible for the behavior of soil microorganisms have not become much more apparent (Papavizas 1973). However, research has been reanimated by the potential loss of MBr and there is some hope that organic amendments will provide protection from disease and enhance seedling growth in forest tree nurseries (Kannwischer-Mitchell *et al* 1994). Although the actual effectiveness of this practice is not proven, the use of such amendments to improve overall soil health and tilth is a worthy goal. Even so, the cost of these amendments could easily make them impractical. Treatments being investigated range from 1 to 4 inches of compost materials (135 to 540 yards³/ac). Although the cost of compost materials vary widely between nurseries under current average demands, which are for maintaining soil organic mater, we suspect that efforts to obtain 8,100 yds³ (or enough material to apply 2 inches to 30 acres) would do little to decrease costs. If the material cost \$7.5 a yard, two inches could cost close to twice as much as fumigation even before the increased costs of fertilizer, insect and weed controls were calculated. Cost/benefit ratio for organic amendments are not available.

Regeneration Success

Based on the average outplanting performances among published studies, grade 1 seedlings can have a present net value (PNV) of \$100 per thousand more than grade 2 seedlings (South and Mexal 1984). Using South and Mexal's estimate, the data presented in Table 5 indicate that fumigation with MBr increased the seedling value per nursery acre \$13,380 without increasing the number of seedlings. However, since values should be based on outplanting performance, what would the impact on the rest of the forest industry be? More conservative projections based on increased growth of outplanted seedlings indicate that treating the entire Glennville nursery with MBr could have increased plantation productivity by 2.3% (Carey and South 1995). Such increases could effect the economy of the South more than the \$35 million loss projected by the USDA for forest tree nurseries after the loss of MBr.

TABLE 5. Treatment comparisons for the 1994 Glennville, Ga. Fumigation trial^a

<u>Treatment</u>	<u>Seedling/ft²</u>	<u>Diameter</u>	<u>#1's/ft²</u>
Dazomet	19.6a	5.2a	14.1a
MC2	22.2a	5.8 b	19.8 b
MC33	20.5a	5.9 b	18.1 b

^aMeans in the same column followed by the same letter do not differ at 0.05.

CONCLUSIONS

1. Methyl bromide has a proven tract record as a safe and effective pesticide in forest tree nurseries and in agriculture in general over the past 40 years. By controlling soil-borne pests, MBr has consistently enhanced the production of larger numbers of improved quality seedlings per unit of land. The reliability of this pest control program has allowed nursery managers to concentrate on improving seedling quality in such areas as size, morphology and nutrient balance, and in increasing seedling uniformity and customer satisfaction.
2. Although not a focus of this note, it seems apparent that MBr originating from agricultural activities has little impact on stratospheric ozone.
3. None of the chemical or cultural methods investigated as possible replacements for MBr fumigations have been as cost effective as MBr. None of the alternatives control the wide variety of soil-borne pests controlled by MBr.
4. The use of MBr has resulted in the production of larger, seedlings that have a positive effect on the economics of plantation forestry across the South.

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Auburn University Southern Forest Nursery Management Cooperative

RESEARCH NOTE 96-2

Testing Alternatives to Methyl Bromide Fumigation At the Winona Nursery

by
Bill Carey

INTRODUCTION

Forest tree nurseries have one of the largest benefit per acre fumigated or per pound of methyl bromide (MBr) used of all crops that utilize significant quantities (Anonymous, 1993) and fumigation, with 2% or 33% chloropicrin, has become almost universal in southern forest nurseries (South, 1992, Carey, 1991). The expected loss of this important management tool after the year 2001 understandably concerns nursery managers. Hopefully, new fumigants, combinations of fumigants, or improved application techniques will provide adequate replacement for current fumigation practices.

Across the country, the improved seed efficiency and seedling quality attributable to MBr fumigation has appeared to be independent of region, soil type, or tree species (Carey, 1994). Unfortunately, recent trials indicate that efficiencies of potential replacements for MBr will be more site specific. This makes preliminary screenings advisable at each nursery.

METHODOLOGY

The Winona Tree Nursery is located near Winona, Mississippi on a silt loam soil (57% silt, 14% clay and 29% sand) with a pH of 5.9. The study area was last fumigated (350 lbs/ac MC33) in 1990 and produced two crops of pine seedlings (1990 and 91) and two cover crops (winter wheat and sudex in 1992 and 93).

The study area is eight beds wide and 600 ft long. Treatments were assigned, within eight adjoining beds containing eight plots each in a standard 8 by 8 Latin square. Treatment plots were one-bed-wide (5ft) by 62 feet long and separated within a bed by 15 foot buffers. Six fumigation treatments, 350 lbs/ac 67% methyl bromide plus 33% chloropicrin (MC33), 300 lbs/ac 70% 1,3 dichloropropene plus 30% chloropicrin (Triform®), 250 lbs/ac chloropicrin (96.5% ai HDPic®), 400 lb/ac metham-sodium, 400 lbs/ac metham sodium plus 115 lbs/ac chloropicrin or 250 lbs/ac dazomet (Basamid®) were applied April 27, 1994. The dazomet was

applied to the soil surface and rototilled immediately into the soil. All other fumigants were shank-injected and covered immediately by plastic tarp.

A single mixed seed lot of loblolly pine (*Pinus taeda* L.) was sown in all study plots May 18, 1994 (21 days after fumigation). Seedlings were counted 35 and 202 days after sowing (June 23 and December 6, 1994). Seedlings within a four-square-foot frame were counted at two systematically located points within each treatment plot. When the December counts were made, more than 25 seedlings were removed from each counted subplot for determination of size and mass. Root collar diameters were measured for 25 seedlings randomly selected from each subplot and these (25) were then oven-dried to a constant weight.

All weeds were counted 58 days after fumigations within the same four-square-foot areas within which seedbed densities were assessed (June 23, 1994). Weed cover was also estimated on a scale of 1 to 10 for the whole plot.

Soil samples were collected from 12 treatment plots two days before fumigation and from all plots (n=64) 58, 130 and 244 days after treatment. Soil was collected at points roughly 1/3, 1/2 and 2/3 into each treatment plot, bulked and transported to the laboratory to be plated and assessed for *Fusarium*, *Trichoderma*, and *Rhizoctonia*.

RESULTS

The Nursery Coop has evaluated fumigation trials at five nurseries over the past three years using the techniques described here. Winona's soil is by far the heaviest among these nurseries. Soils were greater than 90% sand at the other four nurseries compared to less than 30% at Winona (57% silt, 13% clay).

Seedling Quality:

No differences were measured for seedbed densities or in seedling quality among treatments (Table 1). Differences in seedbed densities are usually attributable to disease so a lack of difference is not surprising. Past studies have shown the suppression of chronic, soil born, diseases by MBr for more than two years. Past fumigation and cultural practices over several years have reduced the incidence of low soil diseases. However, there have been differences in seedling quality between fumigation treatments in several studies. No significant seedling quality differences among fumigation treatments is unusual.

Weeds:

Numbers of weeds and weed cover per plot differed among treatments (Table 2). These variables also differed within the study area for column but not for bed location. As expected, MC33 reduced weeds more than the other fumigants.

Table 1. Fumigation effects on seedbed density and seedling development.

<u>Treatment²</u>	<u>Number/ft²</u> (Date)		<u>Seedling Grade¹</u>			<u>Weight</u>	
	<u>6/23</u>	<u>12/6</u>	<u>Dia.</u>	<u>plant</u>	<u>one</u>	<u>cull</u>	<u>total root</u>
Control	26	27	4.2	18.1	3.8	8.5	81.3 17.3
MC33	27	28	4.4	17.5	2.1	10.5	91.9 17.3
HD-PIC	28	26	4.2	16.9	2.9	8.8	80.8 15.8
Triform	28	30	4.1	22.2	2.6	8.2	91.9 16.8
SMDC/Chl	28	28	4.3	17.9	2.9	10.3	91.4 17.0
SMDC	27	28	4.2	19.0	3.3	8.6	85.4 17.6
Dazomet	27	26	4.2	20.0	2.3	6.4	80.9 15.6
lsd ³ 2.7	3.8	0.2	4.5	1.9	3.7	16.3	3.4

¹ Seedling grades of one, cull and plant, respectively, refer to root collar diameters > 4.75mm, < 3.2mm, and > 3.2mm. The numbers reported for grade and for weight are for square foot of bed.

² MC33 is 235 lb/ac 67% MBr + 37% chloropicrin, HD-PIC is 250 lb/ac chloropicrin, Triform = 300 lbs/ac 70% 1,3 dichloropropene plus 30% chloropicrin, SMDC is 400 lb/ac metham-sodium, SMDC/Chl is 400 lbs/ac metham sodium plus 115 lbs/ac chloropicrin, and dazomet is 250 lb/ac.

³ lsd is for SAS ANOVA α 0.05.

Table 2. Weed abundance by treatment 53 days after fumigation.

<u>Treatment¹</u>	<u>Number in 4 ft²</u>	<u>Percent Coverage</u>
Control	13.7 a	38.7 a
MC33	2.3 c	5.9 c
HDpic	6.1 bc	14.4 bc
Triform	4.5 bc	21.2 bc
SMDC	9.5 ab	25.0 ab
SMDC/Chl	2.6 c	11.2 bc
Dazomet	4.6 bc	21.9 bc
lsd ²	5.3	14.9

¹ MC33 is 235 lb/ac 67% MBr + 37% chloropicrin, HD-PIC is 250 lb/ac chloropicrin, Triform = 300 lbs/ac 70% 1,3 dichloropropene plus 30% chloropicrin, SMDC is 400 lb/ac metham-sodium, SMDC/Chl is 400 lbs/ac metham sodium plus 115 lbs/ac chloropicrin, and dazomet is 250 lb/ac.

² lsd and Duncan's means separation are for SAS ANOVA α = 0.05.

Table 3. Colonies of soil fungi on selective media receiving 0.5 ml suspension containing 4.4 mg nursery soil by fumigation treatment and sampling date.

Treatment ²	<u>Fusarium</u>			<u>Trichoderma</u>			<u>Herr's Medium</u>			
	<u>date¹</u>			<u>date</u>			<u>date</u>			
	6/2	3 9/5	12/6	6/23	9/5	12/6	6/23	9/5	12/6	
Control	6.8	10.3	8.0	6.4	5.8		5.1	12.9	12.3	9.6
MC33	2.9 b	3.8 b	2.0 b	10.2 b	10.7 b		10.6 b	10.2	13.7	5.8
HD-PIC	1.5 b	2.9 b	3.7 b	10.7 b	6.6		12.5 b	19.4 b	9.1	22.3 b
Triform	3.7	5.7 b	5.3	11.0 b	7.2		9.0 b	17.7 b	10.6	12.8
SMDC/Chl	1.9 b	1.5 b	3.1 b	6.0	4.5		3.2	6.5 b	9.1	11.3
SMDC	5.4	10.5	8.1	4.8	4.8		3.2	12.6	10.2	10.1
Dazomet	5.2	8.4	7.2	5.3	4.3		3.8	11.2	4.7 b	6.4
lsd ³	2.9	2.4	3.5	3.8	2.3		2.4	5.5	5.9	12.8

¹ Dates 6/23, 9/5 and 12/6 are, respectively, 58, 130 and 244 days after fumigation.

² MC33 is 235 lb/ac 67% MBr + 37% chloropicrin, HD-PIC is 250 lb/ac chloropicrin, Triform = 300 lbs/ac 70% 1,3 dichloropropene plus 30% chloropicrin, SMDC is 400 lb/ac metham-sodium, SMDC/Chl is 400 lbs/ac metham sodium plus 115 lbs/ac chloropicrin, and dazomet is 250 lb/ac.

³ lsd is for SAS ANOVA α 0.05.

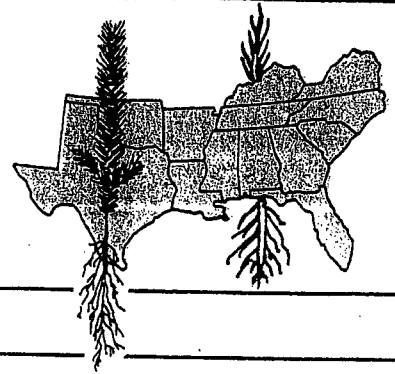
Soil Fungi:

Numbers of colonies of *Fusarium*, *Rhizoctonia*, and *Trichoderma* in soil samples from two days before or 58 days after treatment did not differ for position (bed or columns) within the nursery (Table 2). Numbers of soil fungi, especially *Trichoderma*, should be considered to represent proportional differences between treatments rather than an exact number of cfu's per gram of soil. With that caveat, populations of soil fungi at Winona responded similarly to those at other nurseries. More colony forming units (cfu's) of *Trichoderma* after fumigation with MC33, chloropicrin or Triform (see Table 2) and no increase or a decrease after dazomet has occurred at the other tested nurseries. No reduction in cfu's isolated on Herr's medium after fumigation has not occurred at other nurseries. Because Winona is the only heavy textured soil tested using these techniques this may be normal for this soil texture. Numbers of *Fusarium* cfu's were fewest among treatments that included chloropicrin (MC33, chloropicrin, sectagon plus chloropicrin and Triform).

IMPLICATIONS FOR MANAGEMENT

In pine nurseries, most weeds are effectively controlled by herbicides and weed abundance did not differ among fumigants after herbicide application at Winona. Nevertheless, savings for reducing herbicide applications (both economic and ecologic) could reduce the cost for fumigation. Whether the reduction from 13.7 to 2.4 weeds per 4 ft² (at 35 days after sowing) would reduce herbicide applications would vary between nurseries with such factors as the weed tolerance of the nursery manager and the flexibility of personnel and equipment schedules.

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RESEARCH REPORT 97 - 7

A SINGLE NURSERY TEST OF HOT WATER, 1,3-D, AND METHAM-SODIUM AS ALTERNATIVES TO METHYL BROMIDE

by
William Carey

INTRODUCTION

Fumigants containing methyl bromide (MBr) are widely used to insure seedling quality and production in southern forest tree nurseries. Because MBr will probably not be available in the near future, alternative treatments should be evaluated within the framework of current cultural practices both to acquaint nursery management with necessary techniques and provide estimates for possible changes in seedling growth. One proposed alternative is the use of hot water as a soil treatment. The injection of super-heated water into the top soil horizons may control disease, weed, and insect pests much the same way as MBr. Other alternative substitutes for MBr are the already known fumigation chemicals 1,3-dichloropropene (1,3-D) and Metam-sodium with chloropicrin. The objective of this study was to test hot water and these two chemical fumigants as possible substitutes for MBr and to compare their efficacy against the standard Methyl-bromide/chloropicrin fumigation.

METHODOLOGY

The chemical fumigants and the hot water treatment (HWT) were installed during the Spring of 1994 at the MacMillan Bloedel nursery near Camben, Alabama. The field design compromised total randomization for cost-efficient and safe application of the commercial (MC2) treatment to a contiguous area and the need of current application technology with respect to the HWT (Figure 1). The following treatments were applied:

- 1) Methyl bromide plus 2% chloropicrin (MC2) at a rate of 350 lbs/ac, injected and covered with continuous plastic tarps on March 28.
- 2) Triform® at 350 lbs/ac (1,3-dichloropropene (1,3-D) at 235 lbs/ac plus chloropicrin at 115 lbs/ac, injected and tarped on April 17.
- 3) Metham-sodium mechanically incorporated at 400 lbs/ac, followed by shank injected chloropicrin at 125 lbs/ac and soil surface compaction using a drum-roller.
- 4) Hot water at 110° C (230°F), shank-injected and mechanically mixed by vertical

shaft cultivators to a depth of 6 inches. Approximately 1,700 gal of water were applied to 400 linear feet of nursery bed for the equivalent rate of 37,000 gallons per acre. The boiler unit traveled approximately 44 ft/minute (0.5 mph).

Soil temperatures were recorded for several hours for nursery Blocks 9 and 10 using continuous recording thermometers (Thermographs). Temperatures were recorded in the other four blocks during the 15 minutes after application using hand-held probes that were relocated within a 10-foot section of nursery bed between readings.

Loblolly pine (*Pinus taeda*) was sown the first week of May, 1995. Seedlings per square foot (seedbed density) were determined on June 6 and Nov. 11 using either 3 or 4 samples taken with a 4 ft² counting frame. Seedlings were lifted from these same frames on Nov. 11 to measure size and mass.

Soil samples were collected within each nursery block before treatment (March 21, 1995) and within each treatment block when seedbed densities were determined (June 6 and November 11). Samples were collected across transects within each treatment block using a 3/4" diameter soil probe, bulked and mixed thoroughly. These samples were used to determine soil texture, pH, soil fungi, and nematodes.

RESULTS:

Seedling Development

The large area covered by this study (more than 40 acres) increased block differences more than was anticipated. Soil textures ranged from 65-75% sand, 12-17% silt, and 10-22% clay across the 6 blocks (45.6 acres total area). The average was 73, 14, and 13% sand, silt, and clay, respectively. Soil pH averaged 5.45 with a range of 5.1 to 5.8. In addition, the time of sowing and number of seedlots contributed to variability of germination and seedling development.

Fewer seedlings among the normally reliable "standard-practice-control" MC2 treatment (Table 1) is puzzling and removes an anticipated benchmark for variability among blocks. In June, the MC2 treatment contained fewer seedlings/ft² than any treatment but the control. With 2.5 fewer seedlings/ft², the MC2 treatment was unusually poor compared to its relative performance in other studies. Areas of stunted seedlings within MC2 treatments were determined (based on root morphology and foliage phosphorus) to have insufficient mycorrhizal colonization. Although not believed to affect seedbed density directly, insufficient mycorrhizae unusually indicates "effective" fumigation which could have affected other non-monitored soil microorganisms.

The 1,3-D/chloropicrin and the metham-sodium/chloropicrin treatments ranked among the best for both numbers and sizes. The hot-water treatment improved seedling production compared to the control. Other treatment combinations did not rank consistently for numbers or sizes of seedlings. Bed densities differed between treatments only for the comparison limited to the three treatments included in all six blocks (ANOVA $P = 0.01$). Seedbed densities were negatively correlated with average rcd $\textcircled{R} = -0.54$, $P = 0.02$) and the number of grade-one seedlings/ft² $\textcircled{R} = -0.56$ $P = 0.02$). However, seedling weight per unit area of bed did not differ between treatments.

Seedling weights were analyzed by square-foot of nursery bed to compensate for the tendency for individual size to vary inversely with bed density. Lower bed densities among MC2 treatments compared to controls should and did correlate with larger mean rcd's and more grade-one seedlings. However, within the range of seedbed densities assessed here, per area biomass is reported to decrease with decreases in bed density. Therefore, although the significant increase in individual biomass (mean rcd's and numbers of grade-one seedlings) in MC2 treatments is expected, greater per area biomass is not, and indicates growth enhancement by treatment.

Fungi

Treatment means and lsd's for the three selected groups of soil fungi are presented in Figure 2. Among June samples, cfu's of all three fungi differed between treatments but not between blocks. In November, only numbers of cfu's of Fusarium differed between treatments ($P < 0.05$). The significant correlation between November and June seedbed densities ($r=0.95$ $P = 0.0001$) indicates that little or no post-damping-off mortality occurred in any treatment.

Nematodes

Treatment effects on nematode populations are presented in Table 2. No treatment contained more than 2 pathogenic nematodes per 100 cc of soil in June and treatments did not differ ($P = 0.34$). Pathogenic nematodes increased by November except among MC2 treatments where none were extracted but treatments still did not differ ($P = 0.08$). Numbers of saprophytic nematodes differed between treatments in June ($P = 0.02$) and in November ($P=0.006$). By November, saprophytic nematodes were more abundant among metham-sodium/chloropicrin treatments ($\alpha = 0.05$).

Hot Water Treatment

It was hoped the HWT would raise soil temperatures in the top six inches to approximately 50°C for 15 to 30 minutes. On the large scale, the thermograph data indicated this occurred (Figure 3). The small scale or movable probe data, however, indicate that despite mechanical mixing, temperatures varied about 10°C between "pockets" of soil for five to ten minutes after treatment. The effect of this on soil pathogens within these parts of treated beds is not known. Certainly, the HWC resulted in a larger average seedling size and higher seedbed densities when compared to the control, although this difference did not separate statistically (Table 1).

MANAGEMENT IMPLICATIONS

Using 1994 technology and a treatment rate of 3 to 4 acres per hour, the speed of hot water treatment is not practical to the scale of forest tree nurseries. However, planned modifications for continuous water supply and the ability to treat more than one bed width, could reduce the time required significantly.

The two chemicals tested in this study proved to be suitable substitutes to MC2 as measured by seedling density and development. Metham sodium did not provide the same level of nematode control as the other two chemical treatments.

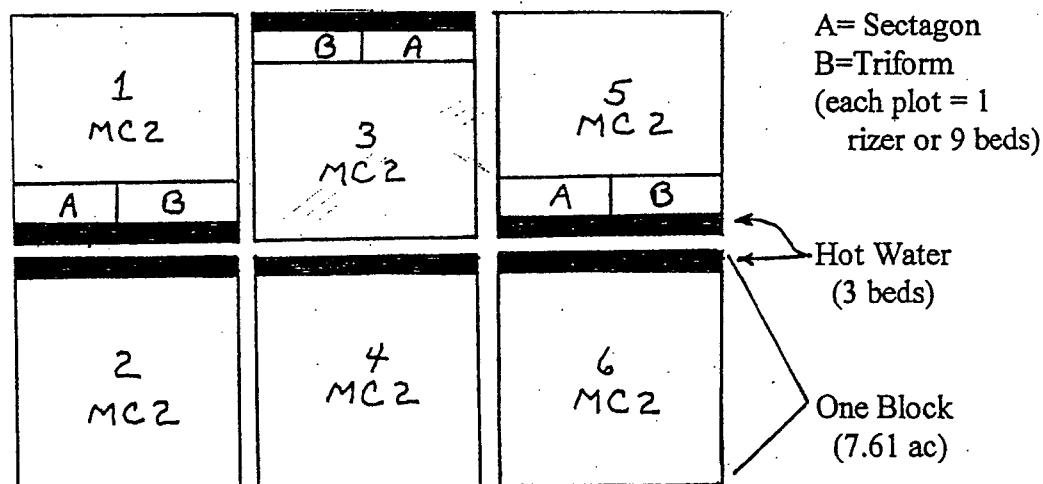
Table 1. Treatment means for pine seedling production by soil treatment at the MacMillan Bloedel nursery near Camden, AL.

N	Treatment	Average rcd	Values per ft ² of nursery bed					
			Bed Density		Grade 1	Oven Dry Weights		
			Spring	Fall	Seedlings	Shoot	Root	Total
6	Control	4.0 c	22.8 ab	22.7 ab	2.2 c	45.3	14.5	60.0
6	Hot Water	4.1 bc	24.1 a	24.4 a	4.7 bc	53.6	16.9	70.5
6	MC2	4.5 a	20.3 b	20.3 b	7.1 ab	55.8	16.7	72.6
3	Triform	4.5 a	24.0 a	22.6 ab	8.2 a	57.4	18.0	75.5
3	Sec/Chl	4.3 ab	24.1 a	22.9 ab	5.2 abc	54.7	15.3	70.1
	lsd	0.24	3.4	3.6	4.7	14.9	4.3	18.1

Table 2. Nematodes (per 100 cc of soil) by treatment at the MacMillan Bloedel nursery.

N	Treatment	Pathogens		Saprophytes	
		June	November	June	November
6	Control	0.5	52.3	108.3 a	164.2 a
6	Hot Water	1.8	46.0	85.7 ab	204.0 a
6	MC2	0.7	0.0	41.3 b	141.0 a
3	Triform	0.0	3.7	41.7 b	253.0 a
3	Sec/Chl	0.0	16.0	68.0 ab	404.7 b

Figure 1. Plot layout at the MacMillan Bloedel nursery.



Soil fungi by treatment and date

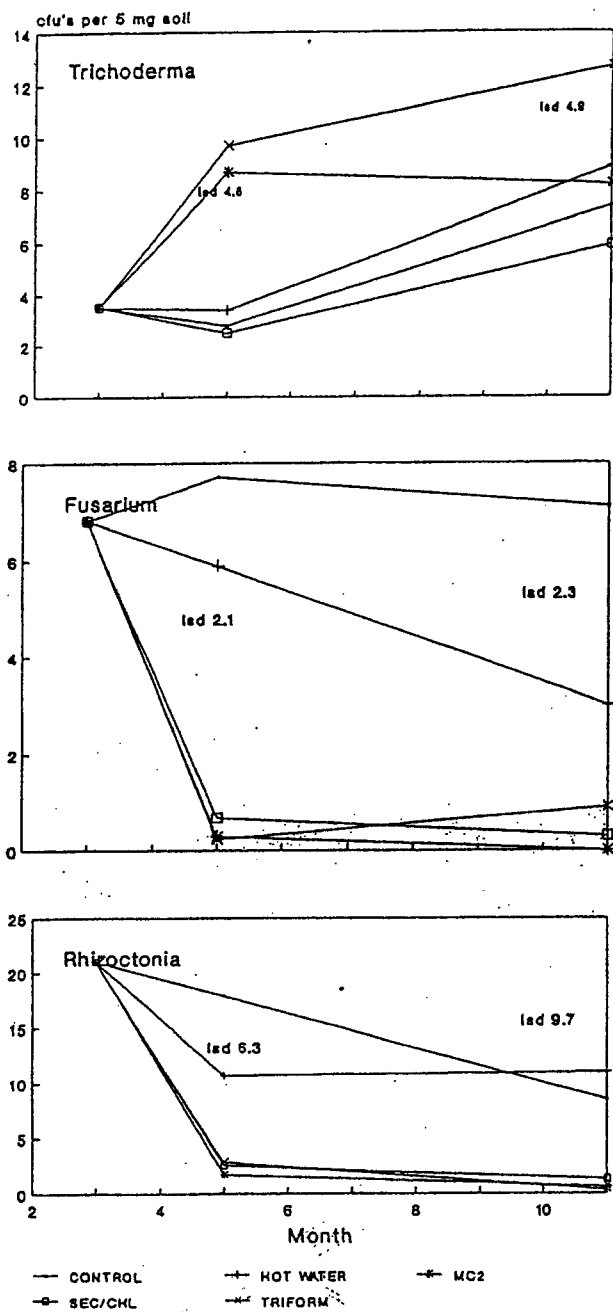
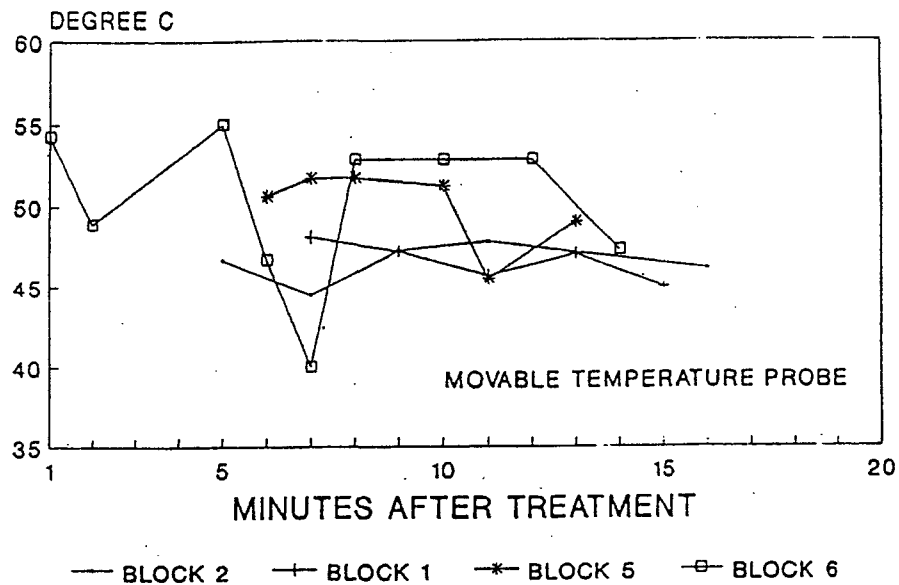


Figure 2. Colony forming units of Trichoderma, Fusarium, and Rhizoctonia by soil treatment and date at a forest tree nursery.



APRIL 5-6

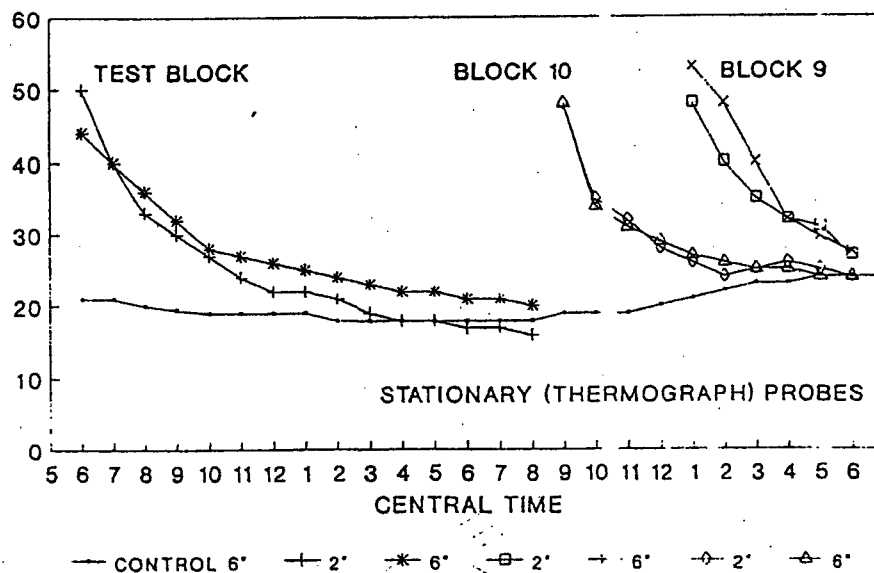


Figure 3. Soil temperatures after shank injecting and mechanically mixing (to a 6 inch depth) 110° C water at a rate of approximately 37,000 gallons per acre.



Auburn University Southern Forest Nursery Management Cooperative

RESEARCH REPORT 98-2

PINE SEEDLING PRODUCTION AS AFFECTED BY FUMIGATION AND PLANT GROWTH PROMOTING RHIZOBACTERIA AT A GEORGIA NURSERY

by

Bill Carey and Scott Enebak

INTRODUCTION

Although methyl bromide (MBr) fumigation satisfactorily controls most soil-born pests at southern forest seedling nurseries its use may be withdrawn or limited after the year 2,000. Alternative fumigants usually have less activity against some category of pests (weeds, nematodes or pathogens) controlled by MBr and their efficacy will vary between nurseries depending on the relative importance of endemic problems. It may be possible to enhance seedling growth without chemical treatments. Plant growth promoting rhizobacteria (PGPR) applied as seed treatments have promoted growth and controlled some soil-born pathogenic fungi on forestry species (Chanway, 1997). This report summarizes seedling production and differences between selected soil fungi (*Trichoderma* and *Fusarium*) and weeds for two 1-0 loblolly and slash pine seedling crops after a single fumigation.

METHODOLOGY

The fumigants, MC2 (300 lbs/ac 98% MBr 2% chloropicrin), and chloropicrin (300 lbs/ac) were each applied to a one third section of two blocks on February 16, 1996 and the remaining (middle) third was not fumigated. On April 9, 1996, seed from four half-sib seedlots of loblolly and from four of slash pine were removed from stratification and half of each was treated with a PGPR preparation of *Burkerholdia cepacia* at the rate of 0.3 ml bacteria per gram of seed. On April 1, 1997, the same PGPR preparation was applied to seed from three of the same loblolly families and to two of the same slash families as in 1996 plus a previously not treated slash family. PGPR treated and not treated of each family was sown in each fumigation treatment. Seedling development was assessed October 1996 and November 1997. Seedbed densities were assessed within two 1-foot-wide frames across beds (4 ft²) within each fumigation by seedlot by PGPR

treatment. Weeds were counted when seedbed densities were assessed. Each fall, the center six drills of each seedbed density plot were harvested and 25 seedlings were randomly selected from each. Root collar diameters (RCD) were measured before tops were separated from roots, oven dried, and weighed.

Fumigation effects on soil fungi in the genera *Trichoderma* and *Fusarium* were assessed as colony forming units (cfu's) / gm soil at three and eight months after fumigation. Soil samples were bulked by treatment across three transects and 0.005 gm subsamples, in 2% water agar, transferred to selective media.

RESULTS AND DISCUSSION

With the exception of initial seedbed density (35 days after sowing) no measured parameters differed ($\alpha \leq 0.05$) by PGPR treatment. Initial seedbed densities differed between treated and not treated seeds for slash but not lob in 1996 and for lob but not slash in 1997. Final seedbed densities did not differ (by PGPR) and initial seedbed densities may reflect changes in germination rate.

Seedling production by fumigation treatment is presented in Table 1. Treatments improved mean RCD, stem weights per bed foot, and numbers of grade one seedlings (RCD > 4.7 mm) in the first crop after fumigation for both species. At the second harvest, only seedling weights differed among lob seedlings and chloropicrin plots produced the largest seedlings. Second crop RCD's no longer differed among lobs but a strong ($p=0.01$) positive ($r=0.81$) correlation to first year treatment by family means continued. Among slash seedlings, RCD's differ both years and were positively correlated ($r=0.72$, $p=0.03$). Slash seedlings were heaviest in MBr plots.

In May 1996, there were fewer weeds in MBr than chloropicrin fumigated plots (0.5 vs 5.6 / 4 ft²). By November that year, most of these weeds appeared to have been eliminated by post emergent herbicides. However, by October 1997 weed numbers, and differences between treatments were again similar to initial counts with MBr plots containing fewer weeds than chloropicrin plots (0.25 vs 5.9 / 4 ft²). Final weed numbers (Oct. 1997), in spite of regular herbicide treatments, were very similar ($r=0.87$, $p=0.02$) to initial counts (May 1996).

Data for soil fungi are presented in Table 2. More cfu's of *Trichoderma* were recovered from fumigated than not fumigated soils at both 87 and 235 days after treatment. Similar increases have been common after MBr or chloropicrin fumigation at forest tree nurseries and for other crops. *Trichoderma* is associated with the biological control of several plant diseases and is considered beneficial for nursery seedlings (South and others 1997).

Cfu's of *Fusarium* decreased with either fumigant and remained low through October 1996, however, by October there were increases among chloropicrin compared to MBr fumigated plots. *Fusarium* is a common plant pathogen often associated with damping-off in pine nurseries. The effects of either fumigant on this fungus should help control damping-off.

MANAGEMENT IMPLICATIONS

This study indicates that chloropicrin substitutes adequately for MBr for some but not all of its normal fumigation benefits. Both fumigants enhanced seedling growth during the first crop and influenced the monitored soil fungi, particularly *Trichoderma*, similarly. Chloropicrin did not (as usual) give the weed control associated with MBr and this could become more serious with subsequent crops depending on the effectiveness of available herbicides for the endemic weeds. There was no indication that seed treatments with the tested PGPR enhanced seedbed densities, seedling rcd's, or biomass.

ACKNOWLEDGMENTS

Hendrix and Dail, Inc. applied the fumigants to the experimental design; Rayonier provided and sowed seed and did all standard practices for both crops.

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Table 1. Effects of fumigation in 1996 on two years of loblolly and of slash pine seedling production at a Georgia nursery.

Pine	Year	Fumigant ^a	Seedlings Parameters		Stems/ft ² by rcd class		
			rcd(mm)	weight(gm) [†]	all	>3.2mm	>4.7mm
Lob	96	None	5.1a	36a	9.3a	8.9a	6.4a
		MBr	5.5ab	51 b	13.5 b	13.4 b	11.5 b
		Chloropicrin	6.0 b	52 b	11.0ab	10.9ab	9.8 b
	97	None	4.3a	49a	13.3a	12.0a	3.9a
		MBr	4.5a	50a	13.7a	12.2a	4.5a
		Chloropicrin	4.5a	63 b	15.1a	13.5a	5.5a
	96	None	4.9a	46a	14.9a	14.1a	8.7a
		MBr	6.0 b	61 b	14.1a	13.8a	11.5 b
		Chloropicrin	5.5ab	58ab	14.2a	13.8a	10.3ab
Slash	97	None	5.4a	65a	13.6a	12.7a	9.6a
		MBr	5.8ab	78 b	13.6a	12.9a	9.7a
		Chloropicrin	6.0 b	73ab	12.2a	11.8a	9.2a

† This is dry weight of seedling stems /ft² of nursery bed.

Table 2. Fungal populations after a February 16 fumigation at a Georgia nursery.

Fungal Genus	Treatment	cfu's [†] / 0.1 gm soil by days after fumigation	
		87 after	235 after
<i>Trichoderma</i>	None	121a	136a
"	MBr	237 b	250 b
"	Chloropicrin	254 b	206 b
	lsd	36	46
<i>Fusarium</i>	None	119a	116a
"	MBr	16 b	16 b
"	Chloropicrin	6 b	59 c
	lsd	26	32

†From 1:200 dilutions.



Auburn University Southern Forest Nursery Management Cooperative

RESEARCH REPORT 98-3

LOBLOLLY SEEDLING PRODUCTION, SOIL FUNGI AND NEMATODES IN THE FIRST
TWO CROPS AFTER FUMIGATION AT THE TEXAS SUPERTREE NURSERY

by
Bill Carey

INTRODUCTION

Methyl bromide (MBr) fumigation has satisfactorily controlled most soil disease problems and enhanced forest tree seedling production throughout the South since the late 1950's. That fumigant is indicted as contributing to stratospheric ozone depletion and its use will probably be withdrawn or limited after the year 2,000. All the alternative fumigants have less activity against at least some of the pests (weeds, nematodes and pathogens) controlled by MBr and should vary in suitability between nursery locations depending on what problems are endemic there. This report summarizes seedling production and changes in numbers of selected soil fungi (*Trichoderma* and *Fusarium*) and nematodes during two 1-0 loblolly nursery crops after a single fumigation.

METHODOLOGY

Three treatments, MC2 (300 lbs/ac 98% MBr 2% chloropicrin), Triform (290 lbs/ac 70% 1-3 dichloropropene and 30 % chloropicrin) and chloropicrin (300 lbs/ac) were each randomly assigned to one third of each of three blocks. Irrigation lines between blocks helped maintain treatment integrity. Blocks were 68 feet wide and 680 foot long and nine beds were sown each year. One bed in each MBr replicate was left not fumigated as a control and half of each chloropicrin replicate was tarped. Fumigation treatments were applied February 22, 1996. The biologically derived nematocide, DiTera®, was applied to the fifth bed of each block during the second crop after fumigation. DiTera was applied at a rate of 2.5 gal/ac (in 40 gal/water) on July 1, 8 and 18 and at a rate 5 gal/ac on September 16 and 26, 1997. The soil at this nursery, near Tyler, Texas is 87% sand.

Loblolly (*Pinus Taeda*) seed were sown on April 16, 1996 and April 22, 1997. Seedling development was assessed November 12, 1996 and October 31, 1997. Seedbed densities were assessed within two 1-foot-wide frames across beds (4 ft²) per fumigation treatment plot. The center six drills of each seedbed density plot were harvested and 25 seedlings were randomly selected from each. Root collar diameters (rcd) were measured before tops were separated from roots, oven dried, and weighed. In 1997, plots in DiTera treated rows were included.

Soil fungi in the genera *Trichoderma* and *Fusarium* were assessed as colony forming units (cfu's)/ gm soil at one week prior to and five and nine months after fumigation. Samples were bulked by treatment plot (n=15) and 0.005 gm subsamples, in 2% water agar, transferred to 6.5 cm diameter Petri plates with selective media. Samples for nematode analysis were collected at the end of each growing season. In 1996, soil samples were collected through treatment plots (n=15) and in 1997, soil was collected at each seedbed density plot and bulked by fumigation and DiTera treatments.

RESULTS AND DISCUSSION

Differences between tarped and not-tarped chloropicrin treatments were not significant so those data were combined. In the first crop after fumigation, there were fewer total and fewer plantable (RCD > 3.2 mm) seedlings in MBr than in control plots. Although MBr fumigation seldom reduces germination or survival a similar, unexplained, reduction in seedling numbers but not growth occurred in Alabama in 1995 where MBr plots contained fewer seedlings than Triform or chloropicrin/Vapam treated plots (Research Report 97-7). Reductions in mycorrhizae can reduce growth, and rarely nursery survival, but this is not indicated here. Seedbed densities did not differ between control, Triform, and chloropicrin treatments and this indicates that there was little disease pressure to affect germination or survival.

Numbers of plantable seedlings were similar among treatments. However, seedling mass per unit area of bed, RCD mean and grade one seedlings (RCD > 4.7 mm) indicate that all fumigants enhanced growth in the first crop after fumigation. The effect did not persist, in the second crop differences between fumigated and not fumigated beds were small. Normally, as seedbed density increases average seedling size becomes smaller and biomass per unit area increases. In the present study, seedbed densities were higher in the second crop 24.5 vs 18.3 /ft² lsd=2.7) but biomass was lower (50.3 vs 80.8 gm/ft² lsd=14.6). Although the growth enhancement of fumigation normally declines in the second year, the absence of any effect (as indicated in Table 1) is unusual.

Data for soil fungi are presented in Table 2. Cfus of *Trichoderma* were similar among fumigated plots at all sample dates but increased compared to controls by November among fumigated plots. Increases in this fungus after MBr or chloropicrin fumigation have been observed at other nurseries and for other crops and abundant *Trichoderma* is associated with the biological control of several plant diseases and is considered beneficial for nursery seedlings (South and others 1997).

Cfus of *Fusarium* decreased after fumigation and stayed low through November 1996 among

fumigated plots, however, at no date did treatments differ significantly and mean cfu's were not reduced by Triform. This common plant pathogen is often associated with damping-off in pine nurseries and the failure of Triform to reduce its numbers is troubling even though disease problems did not occur during the study.

Nematodes from the first crop were analyzed as routine agricultural samples and only plant parasites were reported. The stunt nematode (*Tylenchorhynchus claytoni*) was the only species reported from most samples (mean 19, range 0 - 44 / 100 cc soil). Second crop nematodes were analyzed as research samples and parasitic and saprophytic groups are reported in Table 3. Stunt nematodes remained the most abundant parasites but numbers were still less than has been associated with growth loss of pine seedlings. The nematode extraction technique used in 1997 less efficiently extracts stunt nematodes than that used in 1996 (Rodriguez-Kabana and Pope, 1981). MBr was the only tested fumigant that reduced numbers of stunt nematodes (α 0.05) in the second crop. Saprophytic nematodes averaged 150 / 100 cc and these and the few stubby root nematodes (mean 2.7) did not differ among fumigation treatments. DiTera treatment did not affect the number of nematodes extracted. Numbers of nematodes did not correlate either with seedbed densities, seedling sizes, or weights.

Hopper (1958) reported that "low infestations" of stunt nematodes seemed not to affect pine seedlings but that 75 and 125 per 100 cc soil caused severe injury at nurseries, respectively, in MS and LA. Although within our study area control plots averaged only 30 stunt nematodes / 100 cc, outside this area they were very abundant ($> 1,000$ / 100 cc) among patches of stunted seedlings. These stunted seedlings had symptoms of nematode damage and root inspection for the more virulent lesion nematode (*Pratylenchus* sp) was negative. Since stunt nematodes can buildup in this soil it is unfortunate the alternative fumigants seemed ineffective.

MANAGEMENT IMPLICATIONS

Chloropicrin and Triform enhanced seedling development as well as MBr during the first crop after fumigation but did not suppress numbers of stunt nematodes as well. DiTera did not affect numbers of stunt nematodes.

ACKNOWLEDGMENTS

Abbott Laboratories supplied the DiTera®; Hendrix and Dail, Inc. applied the fumigants to the experimental design; Dr. R. Rodriguez-Kabana consulted and provided nematode extraction and analysis.

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Table 1. Effects of fumigation in 1996 on two years of loblolly production at a Texas nursery.

Year	Fumigant†	Seedlings Parameters		Stems/ft² by RCD class		
		RCD(mm)	weight(gm)†	all	>3.2mm	4.7mm
96	None	4.6a	61a	19.7a	19.1a	6.8a
	MBr	5.5 b	82ab	16.4 b	16.2 b	12.2 b
	Chloropicrin	5.4 b	91 b	18.5ab	18.4ab	12.7 b
	Triform	5.4 b	89 b	18.6ab	18.4ab	13.4 b
97	None	3.8a	54a	23.3a	19.4a	2.8a
	MBr	3.7a	54a	25.5a	19.1a	1.6a
	Chloropicrin	3.7a	46a	23.4a	16.7a	2.4a
	Triform	3.6a	47a	25.3a	17.9a	2.4a

† This is dry weight of seedling stems /ft² of nursery bed.

Table 2. Fungal populations before and after a February fumigation at a Texas nursery.

Fungal Genus	Treatment	cfu's† / 0.1 gm soil by sample date		
		10 before	117 after	230 after
<i>Trichoderma</i>	None	240	260	80a
"	MBr	240	260	340 b
"	Chloropicrin	240	260	280 b
"	Triform	240	260	320 b
<i>Fusarium</i>	None	240	100	100
"	MBr	240	20	60
"	Chloropicrin	240	20	60
"	Triform	240	140	140

†From 1:200 dilutions.

Table 3. Numbers of nematodes by fumigation and DiTera 22 months after fumigation.

Fumigant	Stunt	Stubby Root	Saprophytic	Dorylaimoid
None	31a	2	157	30
MBr	0 b	1	195	5
Chloropicrin	15ab	6	110	10
Triform	19ab	1	142	2
DiTera				
None	12	2	118	10
Yes†	16	4	193	7

†DiTera at 3 application of 2.5 gal/ac and 2 application of 5 gal/ac.



Auburn University Southern Forest Nursery Management Cooperative

RESEARCH REPORT 99 - 2

A COMPARISON OF CHLOROPICRIN, METHAM-SODIUM, AND EPTC COMBINATIONS AS METHYL-BROMIDE ALTERNATIVES AT THREE NURSERIES

by
Bill Carey

INTRODUCTION

The effects of fumigation with chloropicrin and combinations of chloropicrin with metham sodium and or with EPTC were investigated at three nurseries. Although primarily used to increase seed efficiency and seedling quality, fumigation remains important for reducing purple (*Cyperus rotundus* L) and yellow nutsedges (*C. esculentus* L) which have been poorly controlled by other fumigants than MBr (Carey 1994). Therefore, the preemergent herbicide EPTC was included to increase the activity of chloropicrin for nutsedge.

METHODOLOGY

Similar studies were installed at three nurseries (see Table 1 for treatment rates); the Georgia Forestry Commission's Flint River Nursery in 1997, and the Louisiana Department of Agriculture and Forestry's Beauregard Nursery and Rayonier's Glennville Regeneration Center in 1998. All fumigants were applied by Hendrix and Dale Inc. a few weeks before sowing. The four treatments all contained chloropicrin. Seed sources, seedbed densities, fertilization, irrigation and post emergent herbicide regimes were those of the host nursery.

Seedbed densities and seedling sizes were determined in the fall for four-square-foot plots near the center of each fumigation plot. Seedling numbers and oven dry weights were transformed to values per square foot to separate treatment effects from that of seedbed density. Comparisons between nurseries are for loblolly only and for the treatments common to all nurseries.

Comparisons among means are from SAS Duncan's (α 0.05).

At Flint River in 1997, purple nutsedge occurred in the study area and this was assessed in November by collecting all rhizomes ("nuts") within each seedbed density plot. At Beauregard the nutsedge was mostly yellow and this was assessed by hand weeding the entire study area mid season. At Glennville there was too little nutsedge to evaluate.

RESULTS AND DISCUSSION

Chloropicrin plus metham sodium (CMS) significantly increased seedling numbers and growth compared to controls. Averaged for all nurseries, mean RCD increased from 3.6 to 4.4 mm, biomass increased from 0.14 to 0.20 lb/ft² and there were seven more plantable seedlings and 6.5 more grade-1 seedlings/ft² in CMS than in not fumigated plots. Differences between treatments were remarkably similar within the three nursery comparisons presented in Table 1. Total seedlings (Stems), an indication of survival, were similar between treatments and differed only at the nursery with the highest seedbed densities. In all cases, non-fumigated plots contained a smaller average seedling and fewer large seedlings. Although fumigation treatments seldom differed significantly for sizes or numbers of seedlings, treatments with both chloropicrin and metham sodium (CMS) always contained the largest and the most seedlings.

The only significant differences for nutsedge were those between fumigated and control (not fumigated) treatments. Nevertheless, treatment means and trends at both nurseries (Table 1) make it seem reasonable to conclude that both EPTC and metham sodium increase nutsedge control compared to chloropicrin alone.

Seedbed density influences individual seedling and unit area biomass (Mexal 1980). At more than 20 seedlings/ft², each additional seedling increases plot biomass less as some maximum limit of about 0.39 lb/ft² (Mexal 1980) is approached. In this study, biomass per square foot increased as seedbed density increased from 19 at Glennville to 24 at Beauregard but not as it increased again to 28 at Flint River.

Larger differences in mean seedling mass should occur at lower bed densities. At Flint River and Glennville, respectively, 29 and 20 seedlings/ft² in the CMS plots indicate management target densities. At Flint River, there was 22% more total biomass and mean seedling weight was 14% greater. At Glennville, fumigation increased total seedling biomass by 53% and mean seedling weight by 30%. CMS produced four more plantable seedlings (from 18 to 22) and 3.6 more grade-1's (from 0.6 to 4.2) at 29 seedlings per ft² and five more plantables and 11.5 more grade-1's at 20 seedlings/ft².

MANAGEMENT IMPLICATIONS

Seedbed surfaces occupy about 66% or 29,000 ft² of fumigated acres. At a sale price of \$35/M seedlings, this makes each plantable seedling per square foot of bed worth potentially \$1,010/ac. Based on the three nursery average (Table 1) in this study, fumigation increased potential sales \$8,100/ac

Seedlings grown at 20 /ft² have been sold at 66% more than similar stock grown at 25 /ft². The purchaser of such seedlings should be as interested in fumigation history as in bed density. Lowering bed density from 26 to 20 seedling /ft² increased the number of grade-1's per thousand by 129 and by 505 in not fumigated and in fumigated beds, respectively. Buying the low density seedlings from fumigated beds was a much better value.

The treatment averages in Table 1 indicate that in the short term, with no loss of nursery acreage, not fumigating might cost southern nurseries a 33% loss in plantable seedlings per ft² (from an average 21 to 14) or about 330 million seedlings that could sell for about \$11 million. However, even if total seedling production remains adequate there might still be reduced plantation growth associated with a reduction in seedling size. Using the estimates of South and Mexal (1984) fumigation increased PV's (based on expected growth increases associated with the additional grade-1 seedlings) by \$25,900 per nursery acre.

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South, D. B. and J. G. Mexal. 1984. Growing the "Best" seedling for reforestation success. Ala. Agric. Expt. Stn. Forestry Dpt. Series No. 12. 11 pp.

Table 1. Effects of pre-sow soil treatments on seedling production and nutsedge control within nursery and averaged by nursery and by treatment for the Flint River Nursery, the Beauregard Nursery and the Glennville Regeneration Center.

Within Nursery by Treatment				Seedlings Parameters ²					Nutsedge ³
Treatments ¹				rcd	Mass	Stems	Plants	Ones	
MBR	CHL	MS	EPTC						
Flint River Nursery									
0	0	0	0	3.5 c	72 b	26 b	18 b	0.6 b	8.5 a
0	300	0	0	3.6 bc	83 a	29 a	22 a	1.8 ab	4.0 b
0		300	0	6	3.8 ab	87 a	29 a	23 a	3.1 a
0	300	336	0	3.9 a	88 a	28 ab	22 a	4.2 a	0.5 b
0	300	336	6	4.0 a	90 a	29 a	24 a	3.8 a	1.5 b
lsd				0.2	9	2	2.5	2.2	4.0
Beauregard Nursery									
0	0	0	0	3.3 b	70 b	23 a	14 b	0.7 b	485 a
0	250	0	0	3.8 ab	86 ab	24 a	20 ab	1.4 ab	35 b
0	250	0	6	3.6 ab	89 a	24 a	18 ab	0.9 ab	2 b
0	250	253	0	4.1 a	109 a	26 a	23 a	4.9 a	10 b
lsd				0.7	18	3.6	7.8	3.6	326
Glennville Regeneration Center									
0	0	0	0	3.8 c	49 b	17 a	14 b	2.5 b	
0	250	0	0	4.8 ab	71 a	19 a	18 a	10.6 a	
0	250	0	6	4.7 b	70 a	20 a	19 a	9.5 a	
0	250	253	0	5.2 a	75 a	20 a	19 a	14.0 a	
340	7	0	0	5.1 ab	79 a	19 a	19 a	12.2 a	
lsd				0.4	13	3.6	3.1	4.7	
By Soil Treatment n=9									
None				3.6 c	65 c	22 b	14 b	1.5 c	
Chloropicrin				4.1 b	80 b	24 ab	19 a	4.5 b	
" + EPTC				4.1 b	84 ab	24 ab	20 a	4.9 b	
" + Metham Sodium				4.4 a	93 a	25 a	21 a	8.0 a	
lsd				0.3	11	2	3	2.7	
By Nursery n=12									
Flint River				3.7 b	86 a	28 a	21 a	3.2 b	
Beauregard				3.7 b	90 a	24 b	18 b	1.9 b	
Glennville				4.6 a	67 b	19 c	17 b	9.2 a	
lsd				0.3	9	1.8	2.6	2.7	

1) All rates in lbs ai per acre, MBR = methyl bromide, CHL = Chloropicrin 100, MS = Metham Sodium 4.2 lbs ai/ gal, EPTC = Eptam 7EC. Treatments containing Metham Sodium are drum-rolled and others are plastic tarped.

2) Seedling parameters except rcd are per square foot of bed. Mass is grams oven-dry weight, Stems is total seedlings, Plants is Grade 1 plus Grade 2 seedlings and Ones is number of grade one seedlings.

3) Nutsedge at Flint River is rhizomes /ft² and at Beauregard is air dry biomass in lbs/ac.



Auburn University Southern Forest Nursery Management Cooperative

RESEARCH REPORT 00-3

SEEDLING PRODUCTION AND WEED CONTROL BY A POTENTIAL REPLACEMENT FOR METHYL BROMIDE AT THE FLINT RIVER NURSERY

by
Bill Carey

INTRODUCTION

When the superior efficacy of soil fumigation using Methyl bromide (MBr) became apparent, the registration and in some cases reregistration of several marginally less effective alternative fumigants became less attractive. Now, however, with the expected phaseout of MBr the revival of some of these products is likely. Sometimes, where the registration was never completed or subsequently allowed to expire, it is economically justified to reevaluate these chemicals. The present study is an example of this type of research, and the chemical evaluated is designated as MBR-300 which stands for Methyl Bromide Replacement compound number 300.

All the alternative fumigants evaluated by the Coop to date have less activity against at least some of the pests (weeds, nematodes and pathogens) controlled by MBr and probably vary more in suitability between nursery locations depending on what problems are endemic there. This report summarizes seedling production and weed control by MBR-300 and compares that to MBr plus chloropicrin at the Flint River Nursery near Montezuma, GA for the 1999 growing season.

METHODOLOGY

Four treatments, two fumigants with one applied using two methods and a not fumigated control were evaluated at the Flint River Nursery in 1999. The study area, a six-bed-wide riser-line section 740 feet long, was divided into three equal blocks (at right angles to the long axis). The treatments were randomly assigned to positions within each block creating a randomized complete block design. Fumigant plots were 115 ft long and control plots were 15 ft long. The standard fumigation treatment of 200 lbs/ac MBr plus 100 lbs/ac chloropicrin (MC33) was applied through standard straight shanks and plastic tarped. MBR-300 treatment was applied at 336 lbs/ac through special "winged" shanks, that maximized distribution through the soil, followed by a drum roller that compacted the soil surface after injection to decrease the escape of the fumigant. Half of each MBR-300 plot was plastic tarped. Fumigants were applied on March 31, 1999.

Four beds of loblolly (*Pinus taeda*) and two bed of slash (*P. elliottii*) pine seed were sown in the study area on April 22, 1999. Seedling development and weed abundance was assessed May 19 and again Oct. 21, 1999. Seedbed densities were assessed within two 1-foot-wide counting frames across beds (4 ft²) per fumigation treatment by pine species plot. Seedling parameters were converted to units per square foot of nursery bed before analysis. Seedling masses were determined after oven drying for five days at 50°C.

RESULTS

The affects of pre-sow soil treatments on seedling production is presented in Table 1. The MBr treatment and the tarped application of the MBR-300 but not the non-tarped MBR-300 produced significantly better seedling growth than the control. There were more ($\alpha = 0.05$) plantable seedlings and more seedling biomass among the two tarped treatments. The significant improvements in many variables among tarped compared to non-tarped applications of MBR-300, demonstrate the importance of tarping in the efficacy of this compound. The similarity of efficacy between the tarped MBR-300 treatment and the MC33 treatment is very encouraging and suggests further research is justified for MBr-300 using these application techniques. As has been common in Nursery Coop research over the last seven years, there was no indication that seedling mortality varied between fumigation treatments and total numbers of seedlings (survival) did not differ between spring and the fall samples at the nursery.

Table 1. Seedling development by species and treatment at the Flint River Nursery in 1999.

1 a. Loblolly Pine Seedlings

Fumigant [‡]	Treatment Tarp	Seedlings/ft ² [†]		Number/ft ² by Grade [†]			Biomass [§]	
		Apr	Oct	Ones	Plants	Cull	Shoot	Root
MBr	Yes	23	24	1.9	17.5 a	6.3 a	67 a	10 a
MBR-300	Yes	23	23	1.2	18.0 a	4.8 a	67 a	10 a
MBR-300	No	24	24	0.6	11.1 b	12.6 b	49 b	8 b
None	No	22	23	0.0	9.5 b	13.9 b	44 b	9 b
lsd		3.5	3.5	1.9	4.3	4.8	15	1.2

1 b. Slash Pine Seedlings

Fumigant [‡]	Treatment Tarp	Seedling/ft ² [†]		Number/ft ² by Grade [†]			Biomass [§]	
		Apr	Oct	Ones	Plants	Cull	Shoot	Root
MBr	Yes	16	20	4.2	14.1	5.9 a	69 a	9.7
MBR-300	Yes	15	19	4.1	15.4	3.6 b	63 ab	8.7
MBR-300	No	17	19	2.4	13.9	5.3 ab	55 b	8.6
None	No	17	20	2.2	14.8	5.3 ab	54 b	8.9
lsd		2.7	2.4	2.4	2.9	1.9	15	1.7

[†] Number of seedling counted by date.

[‡] Grades one and cull, respectively, are RCD's > 4.8 and < 3.2 mm, Plants are all seedlings > 3.2 mm that is, grade ones plus grade twos.

[§] Biomass is in grams of oven dry seedling.

[¶] MBr is 300 lbs/ac MC33, MBR-300 is 336 lbs/ac of an undocumented compound.

Weeds were not abundant in the study area at the May or October samples. In May, numbers of nutsedge plus spurge differed significantly between blocks but not treatments and ranged from only 0.06 to 0.2 weeds/ft². Weed abundance was similarly low in October and since this was largely a product of post emergent herbicide applications this was not recorded.

MANAGEMENT IMPLICATIONS

The compound tested as MBR-300 was a good candidate for further evaluation to replace Methyl Bromide in southern forest tree nurseries. The efficacy of MBR-300 was not different from the "standard practice control" of tarped MBr at the normal rate, when applied using state-of-the-art equipment that maximized its distribution through the soil followed by tarping. Although in the past this compound was generally found to be inferior to MBr, the application techniques used in the present study appear to have increased product efficiency.

ACKNOWLEDGMENTS

Hendrix and Dail, Inc. supplied the fumigants and did the applications. The Flint River Nursery personnel maintained the study area, sowing and maintaining the beds using standard management practices for the nursery.

Fumigation with Chloropicrin, Metham Sodium, and EPTC as Replacements for Methyl Bromide in Southern Pine Nurseries

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ABSTRACT: The effects of soil fumigation with chloropicrin alone or in combination with metham sodium and or with EPTC on the growth of loblolly pine (*Pinus taeda* L.) seedlings and on nutsedge (*Cyperus* spp.) control were investigated at three forest tree nurseries. Fumigation with chloropicrin plus metham sodium (CMS) significantly increased seedling numbers and growth compared to controls. Averaged among nurseries, mean root-collar-diameter increased from 0.14 to 0.17 in., and biomass from 0.14 to 0.20 lb/ft². This produced seven more plantable seedlings and 6.5 more grade 1 seedlings/ft² in CMS compared to not fumigated plots. Fumigation increased average potential sales \$7,100/ac and increased present values, projected for the growth increases for additional grade 1 seedlings, by \$25,900/ac. Fumigation increased biomass per unit area similarly at tested bed densities (10 to 29/ft²), but at low bed densities (≤ 20 /ft²) the present values associated with grade 1 seedlings increased more than at higher densities. *South. J. Appl. For.* 24(3):135-139.

Methyl bromide (MBr) has been an almost universally used fumigant in southern forest tree nurseries since the late 1960s. It controls problem weeds, insects, and disease organisms. Forest nurseries have historically had large projected economic benefit per pound of MBr used (Anonymous 1993). Therefore, in 1992 when MBr was scheduled to be withdrawn from commercial use in the United States (Jang et al. 1993) by 2001, the Auburn University Southern Forest Nursery Management Cooperative (AUSFNMC) began evaluating possible replacements, concentrating on currently registered alternative fumigants. This research continues, and the efficacies of many fumigant combinations, rates, and application techniques have been tested across the South (Carey 1994, 1996).

More chloropicrin has been applied in forest nurseries than any fumigant except MBr (South et al. 1997). In early AUSFNMC trials, combinations of chloropicrin with either 1-3 dichloropropene or with metham sodium performed better than other alternatives (Carey 1994). However, because of potential regulatory problems with dichloropropene, we recently concentrated on testing rates and application techniques of chloropicrin and metham sodium.

Fumigation is primarily used to increase seed efficiency and seedling quality. However, at some nurseries, fumigation remains an economically justifiable tool for

reducing certain perennial weeds that are resistant to postemergence herbicides (South and Gjerstad 1980). The most important of these are purple (*Cyperus rotundus* L.) and yellow nutsedges (*C. esculentus* L.). Because these weeds have been difficult to control with treatments without MBr (Carey 1994), the preemergent herbicide EPTC was tested, based on results with similar herbicides on agronomic crops.

Materials and Methods

Sites

The study was installed at three nurseries: the Georgia Forestry Commission's Flint River Nursery in 1997, and the Louisiana Department of Agriculture and Forestry's Beauregard Nursery and Rayonier's Glennville (Georgia) Regeneration Center in 1998.

Treatments

All fumigants were applied by Hendrix and Dale, Inc., to well-prepared soil using commercial application equipment. The four treatments all contained chloropicrin (see Table 1), and these were; (1) chloropicrin alone, (2) with metham sodium, (3) with EPTC, and (4) with both metham sodium and EPTC. Chloropicrin plus metham sodium treatments will be referred to as CMS treatments. A nonfumigated control treatment was included at each nursery, and methyl bromide was included as a treatment at Glennville. Within a nursery, each fumigant was used at the same rate in all treatments. At Flint River, chloropicrin was applied at 300 lb/ac, metham sodium at 280 lb ai/ac (Sectagon-42 at 80 gal/ac), and EPTC at 6 lb ai/ac. At

NOTE: William Carey can be reached at (334) 844-4998; E-mail: Carey@forestry.auburn.edu. Supported by the Auburn University Southern Forest Nursery Management Cooperative. Fumigants applied by Hendrix & Dale, Inc. Paper No. 9-996036 of the Journal Series of the Alabama Agricultural Experiment Station, Auburn University, AL 36849-5418. Manuscript received July 15, 1999, accepted January 7, 2000.

Table 1. Effects of presow soil treatments on seedling production and nutsedge control by nursery for the Flint River Nursery in 1997 and the Beauregard Nursery and the Glennville Regeneration Center in 1998.

Treatments*				Seedlings parameters†					
MBr	CHL	MS	EPTC	rcd (in.)	Mass(gm)	Stems	Plants	Ones	Nutsedge**
Flint River Nursery—Loblolly									
0	0	0	0	0.14 c	72 b	26 b	18 b	0.6 b	8.5 a
0	300	0	0	0.14 bc	83 a	29 a	22 a	1.8 ab	4.0 b
0	300	0	6	0.15 ab	87 a	29 a	23 a	3.1 a	1.5 b
0	300	280	0	0.15 a	88 a	28 ab	22 a	4.2 a	0.5 b
0	300	280	6	0.16 a	90 a	29 a	24 a	3.8 a	1.5 b
			lsd	0.02	9	2	2.5	2.2	4.0
Beauregard Nursery—Loblolly									
0	0	0	0	0.13 b	70 b	23 a	14 b	0.7 b	48.5 a
0	250	0	0	0.14 ab	86 ab	24 a	20 ab	1.4 ab	35 b
0	250	0	6	0.14 ab	89 a	24 a	18 ab	0.9 ab	2 b
0	250	210	0	0.16 a	109 a	26 a	23 a	4.9 a	10 b
			lsd	0.03	18	3.6	7.8	3.6	326
Glennville Regeneration Center—Loblolly									
0	0	0	0	0.14 c	49 b	17 a	14 b	2.5 b	
0	250	0	0	0.19 ab	71 a	19 a	18 a	10.6 a	
0	250	0	6	0.18 b	70 a	20 a	19 a	9.5 a	
0	250	210	0	0.20 a	75 a	20 a	19 a	14.0 a	
340	7	0	0	0.20 ab	79 a	19 a	19 a	12.2 a	
			lsd	0.02	13	3.6	3.1	4.7	
Glennville Regeneration Center—Slash									
0	0	0	0	0.19 c	44 b	10 a	10 a	5.9 b	
0	250	0	0	0.22 ac	76 ab	14 a	14 a	10.2 ab	
0	250	0	6	0.20 bc	66 ab	14 a	13 a	9.7 ab	
0	250	210	0	0.24 a	78 a	15 a	14 a	12.7 a	
340	7	0	0	0.22 ab	67 ab	12 a	12 a	10.2 ab	
			lsd	0.03	30	5.4	5.4	5.1	

* All numbers are lb ai/ac, MBr = methyl bromide, CHL = Chloropicrin 100, MS = metham sodium 4.2 lb ai/gal, EPTC = Eptam 7EC. Treatments containing metham sodium are drum-rolled, others are plastic tarped.

† All seedling parameters except rcd (root collar diameter) are /ft² of bed. Mass is grams oven-dry weight, Stems is total number of seedlings, Plants is the sum of Grade 1 (≥ 0.19 in. rcd) and Grade 2 (between 0.12 and 0.18 in. rcd) seedlings, and Ones is number of grade 1 seedlings.

‡ Nutsedge at Flint River is rhizomes /ft² and at Beauregard is air dry biomass in lb/ac. Nutsedge was too scarce to evaluate at Glennville.

Beauregard and Glennville, chloropicrin was applied at 250 lb/ac, metham sodium at 210 lb ai/ac, and EPTC at 6 lb ai/ac. Chloropicrin was shank injected to a depth of 6 in., and if not used in combination with metham sodium, the treatment was plastic-tarped. Metham sodium and EPTC were sprayed on the soil and rotovated to depths of 6 in. Treatments with metham sodium were compacted mechanically ("drum sealed").

At each nursery, the study area was a complete riser-line-section; that is, seedling beds between two irrigation lines (600 to 700 ft in length). At Flint River there were six beds between irrigation lines, and fumigation plots were replicated as completely randomized blocks with each plot across all beds. At Beauregard and Glennville, there were nine beds between irrigation lines, and the study areas were divided into three three-bed-wide blocks and replicated as a randomized complete block. There were three replicates per treatment at each nursery, and all replicate plots were approximately equal in size except at Flint River, where control plots were smaller than fumigated plots. At Flint River, fumigation was complete by April 11, and seed sown May 5, 1997. At Glennville and Beauregard, respectively, fumigations were completed April 7 and April 9, and seed sown May 5 and April 17, 1998.

No attempt was made to influence or to coordinate postfumigation nursery practices. Seed sources, seedbed densities, fertilization, irrigation, and postemergent herbi-

cide regimes were those of the host nursery and were carried out without regard to fumigation treatments with the exception that at Glennville two beds of slash and one bed of loblolly were sown in each three-bed-wide fumigation block.

Seedbed densities and seedling sizes were determined in the fall after scheduled harvesting began at each nursery. Seedbed densities (seedlings /ft²) were determined for 4 ft² plots near the center of each fumigation plot. A minimum of 25 seedlings were lifted from each plot to determine seedling grade distribution [that is, numbers of culls, grade 2's and grade 1's for root collar diameters (rcd's), respectively, < 0.12 in., 0.12 to 0.18 in., and ≥ 0.19 in.]. Seedling numbers (by grade) and biomass (oven-dry weights) were transformed to values per ft² for each counted plot to provide inference for separating treatment effects from that of seedbed density. Except for rcd, all variables were analyzed based on values per unit area of nursery bed.

At Flint River in 1997, purple nutsedge occurred in the study area, and this was assessed in November by collecting all rhizomes ("nuts") within each seedbed density plot at harvest on November 5th. At Beauregard, most of the nutsedge within the study area was yellow nutsedge, and this was assessed by hand weeding the entire study area midseason (July 22), air drying the harvested weeds, and weighing all weeds by plot (August 4). At Glennville in 1998, too few nutsedges developed even in control plots to make comparisons worthwhile.

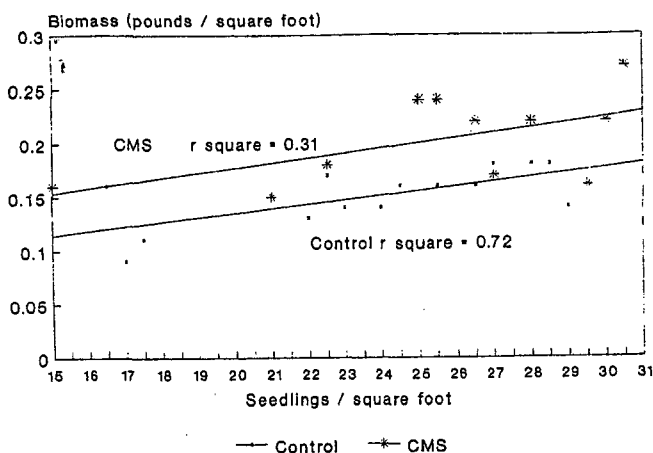


Figure 1. Seedling biomass by bed density for loblolly seedlings at three nurseries in beds either not fumigated or fumigated with chloropicrin plus metham sodium (CMS) and regression lines, by treatment.

Analysis

Treatment means within and between nurseries were compared using SAS ANOVA. The relationship of seedbed densities with unit area biomass presented in Figure 1 was assessed using SAS REG for sampled plot values. Comparisons between nurseries are for loblolly only and for the treatments common to all nurseries. Comparisons among means are from SAS Duncan's ($\alpha = 0.05$).

Results and Discussion

Differences between treatments were remarkably similar within the four nursery comparisons presented in Table 1. Total seedlings (stems), an indication of survival, were similar among treatments within a nursery and differed only at the Flint River nursery, which had higher seed bed densities than the other nurseries. In all cases, nonfumigated plots contained smaller average seedlings and fewer grade 1 seedlings. Although fumigation treatments seldom resulted in statistically different sizes or numbers of seedlings, treatments with both chloropicrin and metham sodium (CMS) always tended to have the largest and the most seedlings.

Statistical inferences for nutsedge control are difficult at best due to the nonrandom distribution that results from vegetative reproduction. At Flint River the nutsedge (rhizomes /ft²) was so abundant (in controls) as to be almost normally distributed. At Beauregard, all nutsedge in the entire study area was collected and weighed. Because of different measures for nutsedge, its abundance was not comparable between nurseries. The only significant differences for nutsedge were those between fumigated and control (not fumigated) treatments. Nevertheless, treatment means and trends at both nurseries (Table 1) suggest that both EPTC and metham sodium increase nutsedge control compared to chloropicrin alone.

Fumigation with CMS significantly increased seedling numbers and growth from that in not fumigated plots (Table 2). Averaged across nurseries, mean rcd increased from 0.14 to 0.17 in., and biomass from 0.14 to 0.20 lb/ft². There were 7 more plantable seedlings and 6.5 more grade 1 seedlings/ft² among CMS treatments than in not fumigated plots.

Biomass increased relatively uniformly among CMS plots across the tested seedbed densities (Figure 1). Such increases are reported for other studies with loblolly pine (Mexal 1980, South et al. 1990). Mexal reported that at up to 20 seedlings/ft², loblolly was relatively free from intraspecific competition, and unit area biomass increased approximately linearly with seedbed densities. At more than 20 seedlings /ft², incremental increases in biomass, both per seedling and per area, decrease as biomass approaches a theoretical maximum limit, which Mexal estimated at 0.39 lb/ft². A similar relationship between number of seedlings and biomass is indicated in the current study, where unit area biomass increased as numbers increased from 19 (Glennville) to 24 (Beauregard) but not as they increased from 24 to 28 (Flint River).

Seedlings may be valued differently by sellers and purchasers. All plantable seedlings may produce similar revenue at the nursery, but larger seedlings should be valued by their purchasers for increased survival and growth after outplanting. South and Mexal (1984) concluded from published data, and South et al. (1985) from 13-yr-old plantations, that the increased growth and performance of

Table 2. Effects of soil fumigation using combinations of chloropicrin, metham sodium, and EPTC on loblolly seedling traits and production at three nurseries: Flint River Nursery (1997) and Beauregard Nursery and Glennville Regeneration Center (1998).

	Seedling parameters [†]				
	rcd (in.)	Mass (gm)	Stems	Plants	Ones
By soil treatment* <i>n</i> = 9					
None	0.14 c	65 c	22 b	14 b	1.5 c
CHL	0.16 b	80 b	24 ab	19 a	4.5 b
CHL + EPTC	0.16 b	84 ab	24 ab	20 a	4.9 b
CHL + metham sodium	0.17 a	93 a	25 a	21 a	8.0 a
lsd	0.01	11	2	3	2.7
By nursery <i>n</i> = 12					
Flint River	0.14 b	86 a	28 a	21.4 a	3.2 b
Beauregard	0.14 b	90 a	24 b	18.2 b	1.9 b
Glennville	0.18 a	67 b	19 c	17.5 b	9.2 a
lsd	0.01	9	1.8	2.6	2.7

* Chloropicrin at 300 lb/ac in 1997 and at 250 lb/ac in 1998, metham sodium 4.2 lb ai/gal at 346 lb/ac in 1997 and at 253 lb/ac in 1998, EPTC at 6 lb ai/ac both years.

† All seedling parameters except rcd are /ft² of seedbed. Mass is grams oven-dry weight, Stems total seedlings, Plants is the sum of Grade 1's (>0.19 in. rcd) plus Grade 2's (0.12 to 0.18 in.) and Ones = number grade 1's.

grade 1 seedlings could increase the present value (PV) of grade 1's more than \$100/M compared to grade 2's.

Seedbed surfaces occupy about 66% or 29,000 ft² of each nursery acre treated with fumigation. At a sale price of \$35/M seedlings, this makes each plantable seedling per ft² of bed worth potentially \$1,010/ac. Based on the three-nursery average (Table 2) in this study, CMS fumigation increased potential sales \$7,100/ac (Table 3) and increased PVs (based on expected growth increases associated with the additional grade 1 seedlings) by \$25,900 per nursery acre.

If unit area increases in biomass are constant, then larger differences in mean seedling mass are to be expected at lower bed densities. At Flint River and Glennville, respectively, 29 and 20 seedlings/ft² in the CMS plots indicate management target densities. At Flint River, CMS increased total seedling biomass by 22% and mean seedling mass by 14%. At Glennville, fumigation increased total seedling biomass by 53% and mean seedling mass by 30%. CMS produced 4 more plantable seedlings (from 18 to 22) and 3.6 more grade 1's (from 0.6 to 4.2) at 29 seedlings/ft² and 5 more plantables and 11.5 more grade 1's at 20 seedlings/ft².

If grade 1 seedlings are valued at \$100/M more than grade 2s (South and Mexal 1984, South et al. 1985) the relative benefits for PV of moving from grade 2 to grade 1 are roughly three times greater than the increased sale value of moving a seedling from grade 3 (cull) to grade 2. Table 3 compares the effects of CMS fumigation on potential sale values and possible PVs of crops at the three different target densities. Although the increase in plantable seedlings and therefore sale value was similar at the three bed densities, larger per-seedling increases at the lower bed density caused proportionately greater increases in PVs. Comparing CMS fumigation with control plots at the highest and lowest bed densities tested, respectively, fumigation increased sale values by \$4,000 and by \$5,500/ac and increased PVs associated with seedling quality by \$13,500 and by \$37,800/ac.

Recognition of the relative superiority of larger seedlings is increasing in the South. Although few seedlings are sold by grade, "low-seedbed-density" seedlings can be purchased from some suppliers. One company offers seedlings grown at 20/ft² at 66% more than similar stock grown at 25/ft². The

present study indicates that to obtain larger seedlings, a purchaser should be as interested in fumigation history as in bed density. Lowering bed density from 26 to 20 seedlings/ft² (Table 3) increased the number of grade 1's per thousand by 129 and by 505 in not fumigated and in fumigated beds, respectively. At a \$0.10 premium per grade 1 (South and Mexal 1984), the additional grade 1's at 20 seedlings/ft² were worth \$12.90 in not fumigated and \$50.50 in fumigated beds. Buying the low density seedlings from fumigated beds was a much better value.

The effects of fumigation on seedling mortality are more frequently reported and more easily appreciated than those on seedling size. This is due, in part, to the importance of survival (seed efficiency) to the nursery manager. In 1997, the South produced and planted more than a billion seedlings. The averages in Table 2 indicate that in the short term, with no loss of nursery acreage, not fumigating might cost the nurseries a 33% loss in plantable seedlings per ft² (from an average 21 to 14), or about 330,000,000 seedlings that could sell for about \$11 million. However, the impacts on plantations should also be considered. If grade 1 seedlings are projected to produce 25% more volume than grade 2's (South and Mexal 1984) reducing grade 1 (Table 2) from 38% in fumigated (8 grade 1's per 21 plantables) to 11% (1.5 grade 1's per 14 plantables) in not fumigated beds could result in 6% less volume production in the resulting plantations even if total seedling production remains adequate.

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Table 3. Effects of soil fumigation on loblolly seedling growth and the potential economic returns as nursery sales and for plantation growth at three seedbed densities.

Density*	Fumigation†	Grade 2††	Grade 1	Per acre \$ return	
				Sale§	Value
29	No	17.4	0.6	18,200	20,000
29	Yes	17.8	4.2	21,300	33,500
26	No	13.3	0.7	14,200	16,200
26	Yes	18.1	4.9	22,300	36,500
20	No	11.5	2.5	14,200	21,500
20	Yes	5.4	14.0	18,700	59,300

* Seedling per square foot where survival was best.

† Fumigation = 300 lb/ac chloropicrin + 346 lb/ac Metham Sodium where density = 29 and chloropicrin at 250 lb/ac + Metham Sodium at 253 lb/ac at densities 26 and 20. For fumigation, a \$1,000 treatment cost is deducted from sale and value expectations.

†† Grade 1 (≥ 0.19 in. rcd), Grade 2 (between 0.12 and 0.18 in. rcd).

§ Sale is expected sale price at \$1,010 per plantable seedling/ft².

|| Value includes a \$0.10 addition per grade 1 seedling based on expected increased growth and survival in plantation.

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Managing Soilborne Pathogens of White Pine in a Forest Nursery

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ABSTRACT

Enebak, S. A., Palmer, M. A., and Blanchette, R. A. 1990. Managing soilborne pathogens of white pine in a forest nursery. *Plant Dis.* 74: 195-198.

In a forest tree nursery, 100% methyl bromide (MB), 100% chloropicrin (CP), combinations of MB and CP, and dazomet significantly reduced populations of soil fungi. Captan, thiram, a combination of captan and thiram, and covering seed with silica sand had no effect on fungal populations in soil. Nine months after fumigation, populations of soil fungi remained lower only in plots treated with MB and/or CP. Preemergence mortality of eastern white pine (*Pinus strobus*) was greatest when seed was covered with silica sand (49%) and least when soil was treated with 100% MB (21%). Postemergence damping-off was greatest when soil was treated with captan (19%) and least when soil was treated with 67% MB and 33% CP (1%). Plots treated with MB and/or CP had the highest seedling stand densities, averaging 232 seedlings per 0.5 m², compared to 125 seedlings per 0.5 m² in plots treated with dazomet and an average of 53 seedlings per 0.5 m² in plots treated with captan, thiram, captan and thiram, or silica sand and in the control plots. Seedling taproots were significantly longer in soils treated with MB and/or CP than in all other treatments. The colonization of root tips by mycorrhizal fungi did not differ significantly among treatments on seedlings examined in June or July 1987.

Damping-off and root diseases that occur in the first year of growth are the primary causes of seedling mortality in forest nurseries in the north central United States. Soils in these nurseries are commonly fumigated with a formulation of 67% methyl bromide (MB) and 33% chloropicrin (CP) to control insects, pathogenic fungi, and weeds (13,16,18). This combination of MB and CP can dramatically increase the yield of nursery seedlings and also improves seedling growth and quality (20,24).

However, use of these fumigants has several drawbacks. In addition to reducing populations of harmful pests, treatment with MB-CP eliminates beneficial mycorrhizal fungi. Mycorrhizal deficiencies may result in stunted, nutrient-deficient seedlings and seedling mortality (3,11,23). Surviving stunted seedlings may not meet grading specifications,

resulting in additional yield losses (4). In addition, fumigation is expensive—application costs exceed \$2,400/ha.

Although many nursery managers believe that the value of bare-root seedlings justifies these costs, Sutherland (21) suggested a combination of alternative management strategies for bare-root nurseries. Such strategies, including both herbicidal weed control and cultural practices that suppress pests, may be more economical than fumigation with MB-CP. We evaluated the relative effectiveness of four MB-CP combinations and several alternative practices for managing diseases caused by soilborne fungi in a forest tree nursery.

MATERIALS AND METHODS

Study area and treatments. The experiment was conducted at the F. G. Wilson State Nursery in Grant County, WI. Damping-off caused by various species of *Fusarium*, *Rhizoctonia*, and *Pythium* is common in this nursery, and a severe root disease of eastern white pine (*Pinus strobus* L.) associated with *F. oxysporum* (S. A. Enebak, R. Camp, and R. G. Collett, unpublished) has also occurred for several years. Thus, we selected treatments that might be effective against these soilborne fungi, and white pine was the tree species used in the study.

A randomized block design was used, with six replications of each treatment. One cultural and eight chemical treat-

ments were applied to plots measuring 2.7 × 5.4 m. The chemical treatments were as follows: 100% MB (MB-100), 67% MB and 33% CP (MB-67), and 33% MB and 67% CP (MB-33), applied at a rate of 392 kg/ha, and 100% CP (CP-100), applied at a rate of 196 kg/ha, each fumigant applied on 4 September 1986 and injected 30 cm into the soil, which was covered immediately with polypropylene and remained covered for 5 days; dazomet, applied on 4 September 1986 as a topdressing at a rate of 280 kg a.i./ha, tilled 30 cm into the soil, packed with a roller, and sealed with 2.5 cm of water from overhead irrigation; captan, applied as a soil drench at a rate of 6 kg a.i./ha on 26 March 1987; thiram, applied as a seed coat at 38 g a.i. and 50 ml of spreader-sticker per kilogram of seed; and captan applied in combination with thiram-treated seed (captan-thiram). Untreated plots served as controls.

For the cultural treatment, two seedbeds (1.2 × 165 m) were established on 19 October 1986, and the hand-sown white pine seed was covered with No. 40 (120 grit) washed silica sand. The plots were then packed with a roller. All other seed plots were then sown mechanically at a rate of 14 g/m². After sowing, seedbeds were covered with screens and left until spring.

Before germination, four permanent subplots (0.5 m²) were established in each plot to evaluate the presence and density of soilborne fungi, preemergence mortality, postemergence damping-off, and seedling stand densities. Areas adjacent to the permanent subplots were designated for seedling collections. Standard nursery fertilization and insect and weed control practices were followed. Overhead irrigation was applied as needed to maintain seedling growth.

Quantification of soilborne fungi. Four soil samples were collected over 9 mo. The first and second samples were collected on 10 August and 19 October 1986, 4 wk before and 4 wk after fumigation, respectively. Soil samples consisted of 20 soil cores (2.5 × 30.5 cm) collected arbitrarily within each plot. The third soil sample was collected just before seedling germination (25 March 1987), and the fourth sample was collected when

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Table 1. Populations (colony-forming units per gram of dry soil) of three fungi and of total soilborne fungi at the F. G. Wilson Nursery before sowing seed (10 August 1986) (BS), at sowing (19 October 1986) (S), before emergence (25 March 1987) (BE), and during emergence (19 April 1987) (DE)

Treatment ^a	<i>Fusarium</i> spp. ^{a,j}				<i>Rhizoctonia</i> spp. ^{a,j}				<i>Pythium</i> spp. ^{a,j}				Total soilborne fungi ^{a,j}			
	BS	S	BE	DE	BS	S	BE	DE	BS	S	BE	DE	BS ⁱ	S	BE	DE
MB-100	1,260 aA	— aB	40 aB	40 aB	11 aA	3 aB	6 abAB	6 aAB	6 aAB	— aB	— aB	— aB	2,730 aA	400 aB	75 aC	97 aC
MB-67	990 aA	33 aB	7 aB	50 aB	10 aA	3 aB	4 aB	5 aAB	7 aA	— aB	— aB	— aB	2,219 aA	268 aB	63 aC	98 aC
MB-33	1,450 aA	— aB	15 aB	90 aB	12 aA	5 aB	5 aB	8 aAB	8 aA	— aB	— aB	— aB	2,077 aA	503 aB	97 aC	150 aB
CP-100	1,550 aA	— aB	— aB	50 aB	11 aA	7 abB	3 aB	4 aB	4 aA	— aB	— aB	— aB	2,118 aA	342 abB	52 aC	129 aB
Dazomet	1,490 aA	220 bB	760 bAB	810 bAB	9 aA	11 bcA	9 bcA	10 abA	5 aA	3 aA	— aB	2 aB	3,039 aA	577 bcA	959 bcB	2,345 bA
Captan	1,230 aA	440 cA	940 bcA	980 bA	12 aA	11 bcA	11 cA	14 bA	7 aA	3 aAB	2 aB	— aB	1,971 aA	548 bcA	1,322 cA	2,962 bA
Thiram	1,650 aA	590 dB	910 bAB	730 bAB	10 aA	12 cA	12 cA	10 abA	7 aA	4 aAB	1 aB	2 aB	2,286 aA	637 cA	894 bcAB	1,798 bAB
Captan and thiram	1,760 aA	580 dB	881 bA	1,070 bAB	11 aA	12 cA	11 cA	14 bA	7 aA	2 aB	5 bA	1 aB	2,256 aA	379 cA	785 bcAB	2,788 bA
Silica sand	1,330 aA	520 cB	1,450 cA	790 bAB	12 aA	11 bcA	9 bcA	15 bA	10 aA	3 aB	6 bAB	3 aB	2,091 aA	566 bcA	1,674 cA	2,224 bA
Control	1,420 aA	550 dB	670 bB	1,120 bAB	12 aA	11 cA	10 bcA	13 bA	2 aA	1 abA	1 abA	1 aB	2,310 aA	405 cA	1,014 bcA	2,664 bA

^aMB-100 = 100% methyl bromide; MB-67 = 67% methyl bromide and 33% chloropicrin; MB-33 = 33% methyl bromide and 67% chloropicrin; CP-100 = 100% chloropicrin.

^bTreatment means followed by the same letter (lowercase for columns and uppercase for rows) do not differ significantly ($P = 0.05$) according to the Student-Newman-Keuls mean separation test.

^cA dash indicates less than 1 cfu/g.

^dColony-forming units per gram in hundreds.

Table 2. Preemergence mortality and postemergence damping-off of white pine seedlings caused by species of *Fusarium*, *Pythium*, and *Rhizoctonia* at the F. G. Wilson Nursery in 1987

Treatment ^a	Preemergence mortality ^a		Postemergence damping-off ^a	
	Number ^b	Percentage ^b	Number ^b	Percentage ^b
MB-100	75 a	21 a	13 ab	4 a
MB-67	77 a	21 a	5 a	1 a
MB-33	78 a	22 a	19 abc	5 a
CP-100	85 a	24 a	9 a	3 a
Dazomet	99 ab	27 a	17 ab	5 a
Captan	123 b	34 ab	70 d	19 c
Thiram	158 c	43 c	37 c	10 bc
Captan and thiram	156 c	43 c	25 abc	7 ab
Silica sand	177 c	49 c	29 bc	8 ab
Control	112 b	31 ab	64 d	17 c

^aMB-100 = 100% methyl bromide; MB-67 = 67% methyl bromide and 33% chloropicrin; MB-33 = 33% methyl bromide and 67% chloropicrin; CP-100 = 100% chloropicrin.

^bData are averages of 24 subplots for each treatment. Means followed by the same letter do not differ significantly ($P = 0.05$) according to the Student-Newman-Keuls mean separation test.

^cPer 0.5-m² plot.

^dPercentage data were analyzed by analysis of variance after square-root arcsine transformation.

seedlings were germinating (4 April 1987). These samples consisted of 10 soil cores collected from within the four permanent subplots. Each composite soil sample was mixed thoroughly before subsamples were selected for quantifying populations of soilborne fungi.

Relative numbers of soilborne fungi were estimated by soil dilution and use of selective media for *Fusarium* spp. (17), *Pythium* spp. (15), *Rhizoctonia* spp. (8,9), and total soil fungi (12,25). Identification of *Fusarium*, *Pythium*, and *Rhizoctonia* spp. was based on the descriptions of Toussoun and Nelson (22), Middleton (14), and Parmeter and Whitney (19), respectively. Relative fungal populations were determined from all six replicates of each treatment and were recorded as colony-forming units (cfu) per gram of oven-dry soil.

Seedling characteristics and stand densities. A germination capacity of 90% was determined for the white pine seed by in vitro and greenhouse tests. With a sowing rate of 14 g/m², approximately 360 seedlings were expected to emerge per 0.5-m² permanent subplot. The

difference between the expected number of seedlings and the actual number of seedlings that emerged was considered preemergence mortality. Seedlings that died in the cotyledon or primary needle stage were classified as having postemergence damping-off. Preemergence mortality and postemergence damping-off were determined on 21 May 1987. Every 4 wk from 5 May to 23 September 1987, the number of seedlings in each permanent subplot was counted to evaluate seedling stand densities.

To determine the pathogens associated with seedling mortality, 10 seedlings with symptoms of damping-off were collected from each plot. Their roots were surface-disinfested for 6 min in a 0.5% sodium hypochlorite solution and then placed on malt-yeast agar (MYA). Plates were incubated at 21 C for 2 days, and hyphae growing from seedlings were transferred to another plate of MYA for identification.

Seedling root growth was evaluated four times during the growing season (on 14 June, 17 July, 13 August, and 14 September 1987) on 10 seedlings per plot

selected arbitrarily and removed from the soil. Root length was measured, the percentage of mycorrhizal root tips was determined by methods of Daughtridge et al (5), and the numbers of healthy (white root cap) and diseased (brown and necrotic root cap) root tips were recorded.

Data were analyzed by an analysis of variance. All data recorded as percentages were subjected to square-root arcsine transformations before analysis. Statistically significant differences among means were determined with the Student-Newman-Keuls test (6).

RESULTS

Quantification of soilborne fungi.

After fumigation, populations of *Fusarium* spp., *Pythium* spp., and total soil fungi fell by 40–100%, regardless of treatment (Table 1). Populations of *Fusarium* spp., however, were lower ($P = 0.05$) in plots treated with MB and/or CP (0–33 cfu/g) than in all other treatments (220–590 cfu/g). Populations of *Fusarium* spp. and total soil fungi were suppressed throughout the sampling period in plots treated with MB and/or CP but rose significantly in all other treatments. Populations of *Pythium* spp. were suppressed in all treatments throughout the sampling period. MB and/or CP reduced populations of *Rhizoctonia* spp. from 10–12 cfu/g to 3–7 cfu/g. Dazomet, captan, thiram, captan-thiram, and the silica sand covering were ineffective against *Rhizoctonia* spp. (Table 1).

Seedling characteristics and stand densities. MB, CP, and dazomet significantly reduced preemergence mortality and postemergence damping-off compared to controls (Table 2). Preemergence mortality ranged from 49% in plots treated with silica sand to 21% in plots treated with MB-100 or MB-67. Incidence of postemergence damping-off ranged from 19% in plots treated with captan to 1% in plots treated with MB-67. *Rhizoctonia*, *Fusarium*, and *Pythium* spp. were isolated from 72, 16, and 12%,

respectively, of the 600 damped-off seedlings cultured.

Seedlings continued to emerge through June 1987 and as a result, seedling stand densities increased in the MB and/or CP treatments (Fig. 1). Seedling stand densities in these treatments did not change significantly after June, whereas stand densities in all other treatments fell markedly (Fig. 1). At the end of the first growing season, seedling stand densities averaged 232 seedlings per 0.5 m² in plots treated with MB and/or CP and 125 seedlings per 0.5 m² in plots treated with dazomet. Other treatments resulted in an average of 53 seedlings per 0.5 m².

Length of seedling taproots increased from 7–9 cm in June to 13 cm in July (Table 3). Taproots continued to lengthen in plots treated with MB and/or CP to almost 15 cm. As seedling roots became more diseased in plots treated with captan, thiram, captan-thiram, silica sand, or dazomet and in control plots, root length decreased to an average of 10 cm (Table 3).

Ninety percent or more of all seedlings, regardless of treatment, had healthy root tips in June (Table 3). Seedlings from captan, thiram, captan-thiram, silica sand, dazomet, and control plots averaged only 53% healthy root tips by July and 22% healthy root tips in September (Table 3).

Treatments did not differ significantly in the percentage of mycorrhizal root tips on seedlings collected in June or July (Table 3). Although the percentage of mycorrhizal root tips of seedlings in plots treated with MB and/or CP increased somewhat in August, by September there were again no significant differences among treatments in this respect.

DISCUSSION

Fumigation of seedbeds with MB and/or CP is economically justifiable at this nursery because of the high potential for root disease on white pine seedlings. Only MB and/or CP treatments were effective in protecting seedlings from soilborne

pathogens throughout the first growing season. Use of these fumigants resulted in the greatest numbers of plantable seedlings and the seedlings with the healthiest and longest roots. Furthermore, there was no evidence to suggest that the fumigants and fungicides adversely affected the colonization of seedling roots by mycorrhizae. Although the fumigants eliminated most of the residual inoculum, spores disseminated after fumigation apparently provided adequate mycorrhizal inoculum. Differences among treatments with respect to the percentage of mycorrhizal root tips observed in August were probably the result of the reduced number of healthy roots. Roots of seedlings growing in plots treated with captan, thiram, captan-thiram, silica sand, or dazomet and in control plots likely became diseased and

decayed faster than they could be regenerated. Consequently, the percentages of mycorrhizal root tips of seedlings in these treatments were lower than in seedlings growing in soils treated with MB and/or CP.

Dazomet was initially as effective as MB and/or CP in suppressing soilborne pathogens; however, populations of soil fungi and disease incidence in dazomet plots began to increase in midsummer, and by the end of the test period, seedling stand densities were significantly lower with dazomet than with the other fumigants tested (Fig. 1). Higher application rates might have given better disease control; however, Hildebrand and Dinkel (10) also reported that dazomet did not provide satisfactory results.

Captan and thiram treatments and

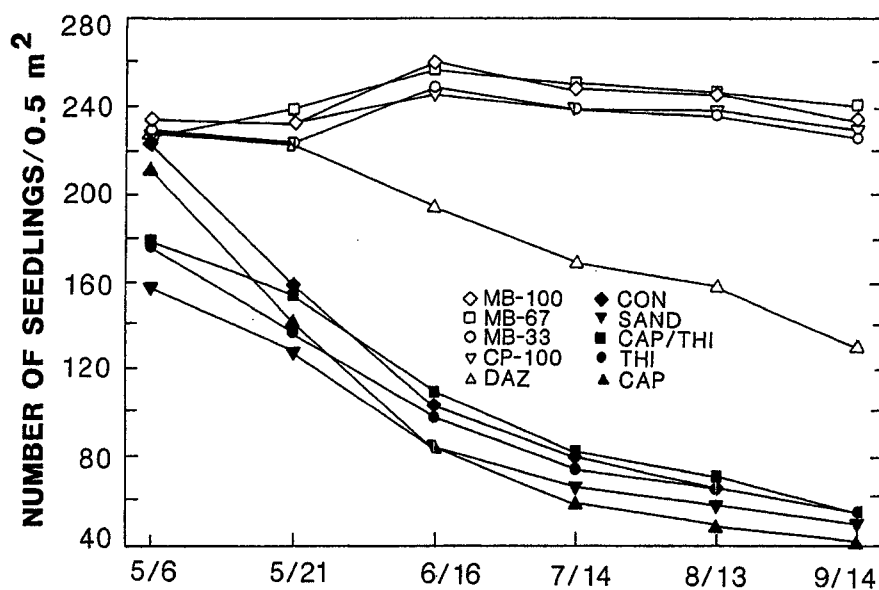


Fig. 1. Stand densities of white pine seedlings in plots treated with eight chemical treatments and one cultural disease management practice at the F. G. Wilson Nursery in Boscobel, WI, in 1987. Values are the means of six plots per treatment. Treatments were as follows: 100% methyl bromide (MB-100); 67% methyl bromide and 33% chloropicrin (MB-67); 33% methyl bromide and 67% chloropicrin (MB-33); 100% chloropicrin (CP-100); dazomet (DAZ); control plots (CON); silica sand (SAND); captan soil drench (CAP); thiram seed coat (THI); and captan and thiram treatments (CAP/THI).

Table 3. Percentage of mycorrhizae (MYC), seedling taproot length (STL), and percentage of healthy root tips (HRT) on white pine seedlings at the F. G. Wilson Nursery on four sample dates in 1987

Treatment ¹	14 June ²			17 July ²			13 August ²			14 September ²		
	MYC (%)	STL (cm)	HRT (%)	MYC (%)	STL (cm)	HRT (%)	MYC (%)	STL (cm)	HRT (%)	MYC (%)	STL (cm)	HRT (%)
MB-100	2.4	8.3	98	33.4	12.3 abc	88 ab	33.8 ab	13.5 abc	85 ab	24.8	14.7 a	68 a
MB-67	1.1	8.4	98	34.0	12.4 abc	98 a	40.1 ab	13.8 a	97 a	29.0	14.8 a	72 a
MB-33	2.3	7.7	98	29.6	12.9 ab	95 ab	42.9 a	13.8 a	95 a	33.8	14.2 abc	76 a
CP-100	1.7	7.9	96	30.0	13.1 a	98 a	39.9 ab	13.6 ab	95 a	24.8	14.6 ab	55 ab
Dazomet	3.5	8.0	98	23.3	11.9 bc	73 bc	31.1 ab	13.7 a	63 bc	41.6	12.2 bcd	31 bc
Captan	3.2	8.2	90	25.3	11.3 c	41 cd	17.7 bcd	11.8 cd	40 c	35.3	9.0 e	8 c
Thiram	5.7	7.2	93	26.1	11.4 bc	56 cd	22.8 d	11.0 d	41 c	37.3	10.8 de	18 c
Captan and thiram	6.6	7.7	95	24.8	11.1 c	38 d	22.7 cd	11.2 d	46 c	31.5	10.1 de	16 c
Silica sand	3.4	8.6	95	28.9	11.8 bc	56 cd	21.2 cd	11.8 cd	45 c	38.8	11.7 cde	38 bc
Control	4.0	8.0	98	28.4	11.8 bc	51 cd	20.8 cd	12.0 bcd	45 c	36.6	10.5 de	20 c

¹MB-100 = 100% methyl bromide; MB-67 = 67% methyl bromide and 33% chloropicrin; MB-33 = 33% methyl bromide and 67% chloropicrin; CP-100 = 100% chloropicrin.

²Treatment means followed by the same letter within a column do not differ significantly ($P = 0.05$) according to the Student-Newman-Keuls mean separation test. No differences were detected for any variable on 14 June or for percentage of mycorrhizae on 17 July and 14 September.

covering the seed with silica sand were not effective in reducing disease. Pre-emergence mortality was greatest when seed was treated with thiram. Phytotoxic effects of thiram may have reduced germination, as has been previously reported (2).

Interest is increasing in reducing the uses of chemical pesticides, particularly fumigants, in forest tree nurseries. Many questions remain unanswered concerning the health risks to both humans and wildlife (1) and the long-term effects on soil microflora (23). Still, many nursery managers routinely fumigate seedbeds to avoid potential disease outbreaks. At the Wilson nursery, the value of the seedling crop (about \$250,000/ha at rotation) compared to the cost of fumigation (\$2,400/ha) justifies the use of MB and/or CP on soils that are "addicted" to fumigation. However, fumigation may not be needed in all areas of the nursery or in every nursery. A recent study we conducted at a northern Wisconsin nursery (7) demonstrated that fumigation with dazomet increased the incidence of stunted, phosphorus-deficient white spruce seedlings, whereas covering seed with sand produced the most normal-sized, healthy seedlings. Sutherland (21) reported that nurseries in British Columbia are seldom fumigated unless they are newly established in agricultural soils.

At present, there are no guidelines for predicting outbreaks of diseases caused by soil fungi in forest tree nurseries. Thus, it is difficult for nursery managers to determine the risk of specific diseases and adapt their treatment schedule accordingly. If forest tree nurseries are to move toward an integrated approach to disease management, a better understanding of pathogen biology and seed quality is needed as well as the development of effective, economical, and

environmentally sound alternatives to fumigation.

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should not be attempted on peppers or strawberries since they are especially sensitive to the chemical and should be closely monitored on all other crops."

Weed Control

Plantpro 45 does provide some weed control, according to Burelle's study. Multiple greenhouse experiments on weed infestation levels in naturally weed-infested soil showed that Plantpro 45 has potential to control one of Florida's major herbaceous weed species in vegetable crops: purslane (*Portulaca oleracea*). Further studies on the herbicidal effects of Plantpro 45 confirm significant reductions in populations of nightshade, purple and yellow nutsedge, and crabgrass. High-foliar applications of Plantpro 45 on emerged weeds, followed by rototilling prior to planting, provided effective control of weed species without phytotoxic effects on tomato when an interval of 21 days was allowed before planting and adequate soil moisture was maintained between application and planting.

In contrast, in Nelson's 2001 California tomato trials mortality of annual bluegrass and common purslane buried 6 inches deep prior to application of Plantpro 45 was significantly lower, relative to the methyl bromide/chloropicrin standard, and not statistically different from that of the untreated control. Further, mixed results

were observed in the 2000 Florida tomato trials. At the Lake Jem trial site, the combinations of Plantpro 45 + metam (applied as a bed-top broadcast spray strictly for weed control) did not significantly control yellow nutsedge. However, at the Live Oak trial site, the Plantpro 45 (1X) + metam (metam again used strictly for weed control) combinations reduced the incidence of this weed species to a level comparable to that of the methyl bromide/chloropicrin standard.

Seed Treatment

In a different application, Plantpro 45 seems to also provide some efficacy as a seed treatment. Burelle worked with an oriental-vegetable grower who had a problem with *Fusarium*. "Plantpro 45 has good potential as a seed treatment," says Burelle. Further studies are needed.

Technical Report

Methyl Bromide Alternatives and Their Current Limitations in Florida

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While there are many limitations to the adoption of methyl bromide alternatives in Florida, those limitations are much different from the principal ones in California in that they are not State regulatory driven, at least

not at this time. Telone products, including Telone II (1,3-dichloropropene) and Telone C-17 and Telone C-35 (mixtures of 1,3-dichloropropene and chloropicrin), constitute the most likely replacements for methyl bromide in many crops in Florida, including vegetables and ornamentals.

Large-scale trials have demonstrated these products on grower farms, especially tomato farms. One of the main obstacles for adoption of alternatives is nutsedge control, and most of the currently available alternatives either provide no control or erratic performance in Florida soils. Tillam has been identified as a herbicide which can be used in conjunction with Telone to provide nutsedge control; however, it is only labeled in tomato and has produced crop damage in some cases. In general, it is felt that these instances of phytotoxicity were the result of improper application or inadequate soil incorporation, as performance has been acceptable in most of the large-scale trials conducted on grower farms. Tomato growers are fortunate in this regard for they have an effective herbicide; however, there are many crops where herbicide options are few, including pepper, eggplant, and cucurbits like watermelon.

Ornamental growers, such as producers of caladiums and cut flowers, have seen little research on their crops and thus are much farther behind tomato

and pepper in the selection and development of alternative strategies.

Telone products have two problems, and these are shared by some of the other alternatives: excessive personal protective equipment (PPE) requirements and setback or buffer space requirements. Buffers of 300 ft. from occupied structures are not a problem for most tomato growers, but for the bulk of the Florida strawberry industry, they are a major deterrent. Most of the production is situated in the Plant City area of Florida. Plant City has become a bedroom community of one of our largest cities, Tampa, and berry fields are generally located within what has become residential areas. Some fields have housing developments on three sides and a road on the fourth. The average strawberry field is 20 acres or less. The arable area of a 20-acre field gets very small when a 300-ft. buffer is imposed, and even smaller if it is interpreted as commencing not from the actual dwelling but from the property line. Thus, Florida strawberry growers do not feel that Telone products are a viable alternative for them. Telone may be efficacious and result in good fruit production, but the buffer may render it impractical for berry growers.

While all seems positive for tomato growers, they do share a common problem with other producers who may rely on Telone products, and that is the

PPE issue. The use of a full-face respirator, rubber gloves, and boots and coveralls all but kills any chance of Telone being used in Florida, especially during the fall season. Our tropical to subtropical climate makes it extremely difficult to work in the required PPE, and heat stress becomes a major issue. Realistically, heat stress may not be a problem because workers are not likely to work under those conditions; thus the real problem would be an inability to fumigate soil for crop production and the resultant economic hardship the grower would experience.

In an effort to deal with or circumvent the PPE issue, those of us working in Florida have investigated broadcast application as an alternative to in-bed application of Telone products. Broadcast application would involve one person in an air-conditioned tractor cab with appropriate PPE and carbon filtration of recirculating air, thus greatly reducing the impact of PPE to a manageable level. While this sounds like a good idea, little data exist for the efficacy of Telone and chloropicrin mixtures when applied to nonbedded soil without polyethylene mulch covering it.

This launched a new wave of research activity wherein broadcast was compared to in-bed applications of Telone C-17 and C-35. Telone II (1,3-D) has been applied broadcast or in-bed without mulch in potatoes for years, and nematode control

efficacy has been well documented. The real question was not so much whether Telone (1,3-D) would work, but rather whether chloropicrin would work under nonmulched conditions. There was some concern that the higher vapor pressure of chloropicrin would allow it to escape too quickly to kill pathogenic fungi near the soil surface.

Several large-scale trials were conducted on grower farms, and disease control appeared to be comparable between the two application methods, but anecdotal information suggested that some diseases may not be controlled as well as *Fusarium* wilt race 3 appeared to be controlled in these trials. Results of small-plot experiments with tomato last fall and again this spring demonstrated that disease control could be compromised. As a result, most grower trial applications now consist of Telone II or Telone C-35 broadcast with additional chloropicrin applied to the soil in the bed at the time of bed formation. Some cases exist where the application of chloropicrin both broadcast and in-bed is beneficial.

Broadcast application appears to be the answer to the PPE issue, but it in itself introduces other potential problems. In order to make the application, allow sufficient time for the product to work and dissipate, then re-enter the treated field, form beds, and wait for the dissipation of chloropicrin, a

grower must allow at least 3 weeks for what once required 10 days to 2 weeks with methyl bromide. Summer, when fumigant is being applied for fall production, is the time wherein most of the rainfall for the year occurs in peninsular Florida. This can greatly disrupt soil fumigation activities and result in even greater delays in planting in August and September, thus making it more difficult for growers to develop and adhere to any type of production schedule.

During December, January, and early February, when soil fumigants are applied for the spring crop, soil moisture often is low and this extra time for fumigation increases irrigation water needs by increasing the time over which it is necessary to maintain field moisture at the point required for good biological activity. Since growers are budgeted by the water management districts for water consumption, this reduces the quantity of water available for use by the crop.

The spring production season is Florida's dry season and rainfall is sparse; thus growers rely heavily on well water for irrigation during what is the largest production season. If the pre-wet period is too short, soil-borne pests may be inactive and more difficult to kill, and fumigant failure can occur. This was the situation on several farms in Florida this spring, and rootknot nematodes were a problem even in fields fumi-

gated with methyl bromide. If a grower uses too much water for initial land preparation and fumigation, he may exhaust his permitted quantity before the crop is ready for harvest.

One of the big advances to come out of the broadcast application effort has been the tremendous improvement in application equipment. Previous equipment left much to be desired and resulted in erratic performance in some trials. Many different pieces of equipment were tried before the ultimate winner would be identified.

Today, all broadcast applications in research trials in Florida are being made with what is known as the Yetter rig. This equipment, manufactured by Yetter Equipment Co., consists of a series of 30-inch coulters with a forward-swept knife or chisel behind each one with a small "beaver tail" on it, and behind that rolls a set of press wheels which seal the soil surface. The coulters are positioned 1 foot apart. This equipment was pioneered in Florida by John Mirusso, who first saw it at a farm show in the northeast where it was being used for delivery of liquid manures.

Use of this equipment has resulted in much more uniform results and improved efficacy. One of the big advantages of the Yetter rig is that it places the Telone about 12 inches deep where nematodes may escape the effect of the more typical 6

to 8 inch deep applications. In addition, it does not drag plastic mulch and string around a field creating large chisel tracks and the resultant loss of fumigant. Instead, the coulter cuts through this and other debris and provides a more narrow kerf which is easier to seal.

While we have worked a lot on minimization of the impact of PPE by developing broadcast application of Telone, we also have investigated application of fumigants through the drip irrigation system as a means of improving delivery and handling and reduction of worker exposure and the negative implications of PPE requirements.

Applications through drip irrigation tubing would not only reduce the impact of PPE by reducing the number of people involved and allow development of a closed delivery system, but it also would allow fumigant delivery for "double cropping" where the old polyethylene mulch and drip tubing are being used for a second crop in the same beds.

Drip application of any fumigant is a challenge in Florida's sandy soils. Most of our production soils are classified as fine sands with less than 1 percent organic matter, no clay, and very little silt. These soils tend to be droughty and do not favor lateral movement of water or other liquids.

Several years ago drip delivery of Telone was attempted in research trials in Florida and it was not successful. Since that time we have studied the delivery and distribution of water via drip irrigation tubing and have a much better understanding of the downward and lateral movement of water in beds and have investigated multiple tubes, adjuvants, water volumes, pressures, and run times to understand what might improve the delivery of a water-soluble pesticide in our soils.

We now feel we can achieve better results than in the past, but one obstacle still remains: weed control in the bed.

While Telone may provide the nematode control we need, it will not control weeds like nutsedge. We still need a herbicide or some other product which can give us this control.

Metam may be an option for our weed control needs, but its performance has been erratic in past research in Florida, and the one thing growers require of any alternative is consistency.

Much research has been conducted on the application of metam in Florida, recognizing that proper application was the key to improved efficacy. Decreased chisel spacing, high-pressure injection, disk incorporation, rototiller incorporation, delivery through the drip irrigation system, and many other techniques have been investigated, but the one which has been the most efficacious has

been rototiller incorporation followed by either immediate bed formation or power rolling the soil surface to seal it.

Drip irrigation delivery has resulted in narrow bands of nutsedge control in the past, but just as was true with Telone a lot depends upon the actual mechanics of the application and we still have a lot to learn. Drip delivery would be more acceptable to most growers if we could improve efficacy, because rototillers are slow, require a lot of horsepower, and few growers own one.

A few growers who have experimented with metam application on a broadcast basis followed by bed formation soon afterward have complained about the fumes and had problems getting their labor to stay on the job. At least one Florida grower is using it in this fashion. Overall, we still have work to do to improve application technology for metam.

A final problem identified with metam is the volume of product required per acre and the need for delivery and storage facilities for a large farm. One hundred acres of tomatoes would require 7,500 gallons of metam, and that is a lot of product to handle. Application through the drip irrigation system would make that a more manageable task, but storage and delivery problems would still exist to some extent. Hopefully, there will not be any surprises in the form of PPE or

buffer zones for metam or chloropicrin when they go through re-registration.

Chloropicrin's future is tied to partnering with Telone for the most part, as alone it is not considered an effective nematocide and provides poor to no weed control. While it is an excellent fungicide for soil-borne pathogens, soil-borne pest control needs are seldom only diseases and are usually a complex of disease with nematodes or weeds or all three combined.

While there are other products being considered as potential alternatives, Telone and chloropicrin are the most likely immediate successors to methyl bromide. Lack of enough data, efficacy problems, and the lack of handling experience with many of these other products make them less likely to become common "household words" in the near future.

The last impediment I would like to discuss is what I call a grower's "comfort level." I asked two of my best tomato grower cooperators if they were comfortable with Telone C-35 plus Tillam herbicide. Each told me the same thing: "I have seen it in your experiments each season here on my farm for at least the last 5 years and the results have been good. I don't think we have had any problems with it or lost much production, if any, but when you ask me if I am comfortable with it, I have to say I am not. I know what

methyl bromide will do because I have used it for many years and there is a lot to be said for the short time interval between application and planting and the wide range of conditions under which I can apply it and still get acceptable control. Use of Tillam makes me nervous because I am not used to applying a herbicide, and my experience with herbicides has been to kill things and I have even damaged tomatoes with it. Am I comfortable with this as an alternative? No. That does not mean that I cannot become comfortable with an alternative, but right now I am not comfortable with this and will have to ease into it slowly."

Comfort is that feeling we have from knowing something well. This level of knowledge is only attained through prolonged exposure and positive experiences. Comfort will not come

overnight, and any negative experience can set back the progress made to date tremendously. This is why as scientists we must try to anticipate the problems and address them before they reach the grower. Additionally, we need to work closely with growers to introduce them to the alternatives we recommend and any other new technology associated with their use to assure an easy transition so there are viable alternatives with which our growers feel comfortable. Only then is our job complete.

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Individual Choice and Regional Acreage Response to Cost-Sharing in the South, 1971-1981

IAN W. HARDIE
PETER J. PARKS

ABSTRACT. Total acreage responding to a given economic incentive is a key measure of the effectiveness of many government forest land-use programs. Examples are the FIP and America the Beautiful programs. Acreage response depends both on landowner behavior and on land characteristics. Prediction of this response for new or untried government incentives consequently requires simultaneous estimation of landowner land-use decisions and of the number of acres affected by the decisions. A method to predict aggregate acreage response to proposed land-use programs is described in the paper. This method is illustrated by an analysis of how cost-sharing could have affected NIPF owner investment in pine regeneration on harvested lands in the South in 1971-1981. Results show that cost-sharing may have encouraged 70% of the regeneration investment observed during the period, and that changes in the cost-share incentive would have been an effective way to change the amount of pine acreage planted or seeded in the South during this period. Application of the method to proposed future programs would require a new area frame sample survey. *FOR. SCI.* 37(1):175-190.

ADDITIONAL KEY WORDS. Nonindustrial private forest landowner, southern pine regeneration, econometric analysis, policy response analysis, area frame sample.

SEVERAL GOVERNMENT PROGRAMS OFFER ECONOMIC INCENTIVES to encourage active management on nonindustrial private forest (NIPF) lands (USDA Forest Service 1988, Alig et al. 1990). Among these are the Agricultural Conservation Program (ACP), the Forestry Incentives Program (FIP), the Conservation Reserve Program (CRP), and the Tree Assistance Program (TAP) (Gunter and Ogden 1989). State forestry cost share programs also exist in 14 states (Bullard and Straka 1988). Furthermore, subsidies to plant trees are an important consideration in the proposed "America the Beautiful" program (USDA Forest Service 1990). Since participation in such programs is voluntary, program effectiveness depends on private owner decisions. In the case of cost-sharing, the participation decision is also an investment decision, for the qualifying owner must commit economic resources to the regeneration or improvement of a forest site.

Although the decision to participate is an important aspect of a voluntary program, the number of participants is not always the best measure of the program's effectiveness. When its purpose is to increase timber supply, shift land use from farm to forest, preserve natural lands, or create forest carbon sinks, the most direct measure of effectiveness is the number of acres affected by the program.

Assessment of such programs requires knowledge of both the number of landowners who would participate and the number of acres that would be affected by

to participation. But obtaining the acreage response from knowledge of typical landowner participation decisions is not trivial. Land characteristics are heterogeneous across owners, and may cause identical owners to produce different acreage responses to a given economic inducement. The aggregation of acreage for such owners is an example of the classic heterogeneous capital aggregation problem of economic production theory (Sato 1975, Chambers 1988). This problem is known to be one of the most intractable encountered in economic analysis.

In addition to the heterogeneous input aggregation problem, landowner participation decisions may also vary with motives for owning forestland (Binkley 1981, Hyberg and Holthausen 1989). When diverse motives exist, different participation decisions may be obtained for identical forest sites. Thus the total acreage response to a land-use program can be affected by the distribution of landowner motives and by the distribution of forest site characteristics.

This paper develops a way to simultaneously estimate the potential landowner and acreage response to prospective economic incentives. Typical NIPF owner response has been successfully estimated in previous studies (e.g., Boyd 1984, Royer 1987). But these landowner decision studies have not been extended to the estimation of regional acreage response. Regional acreage response has been successfully estimated in studies based on aggregate land-use data (e.g., Alig 1986, Brooks 1985). But these estimates depend on landowner decisions prevailing during the data period. They do not capture changes that might be induced by a new policy. Simultaneous determination of the two responses is necessary to analyze the potential effectiveness of new land-use incentive programs.

The proposed analytical method depends on use of an area sample frame to solve the heterogeneous input aggregation problem. This use of the area frame is documented for the United States Department of Agriculture annual agricultural land-use survey (Houseman 1975). To our knowledge, however, the area sample frame has not been used as part of a method to estimate potential acreage response to economic inducements. The following development will show how this can be done.

Description of the analytical method is organized as follows. First, the type of statistic needed to analyze program effectiveness with area frame sample data is presented. This statistic is derived in the appendix to the paper. Then a discrete-continuous choice econometric model is developed that can be used to estimate two of the components comprising the statistic. The final component—the set of expansion factors used to generate regional totals from the sample estimates—is obtained as part of the area frame sampling procedure.

The method is then applied to estimate the effect selected government cost-sharing programs could have had on the regeneration of harvested NIPF pinelands in the South. Empirical results are confined to 1971–1981, the survey period of the only area frame sample that has been drawn for forest land use (Fecso et al. 1982). Similar results could be obtained for present policy proposals if their potential value justifies the expense of a new area frame sample survey.

A SOUTHERN PINES REGENERATION MODEL

The statistics derived from an area frame survey are designed to describe how land is being used during the survey period (Fecso et al. 1982). As a first step

toward predicting how acreage might be used in a hypothetical situation, the area frame statistic is converted to a form suitable for drawing inferences from area frame data. As the appendix to this paper shows, this inferential statistic is of the form:

$$\hat{S}_i = \sum_{k=1}^K P_{ik}(x_k) \cdot E(A_k(x_k)) \cdot M_k \quad (1)$$

where \hat{S}_i is the total acreage in the region in land use i ($i = 1, \dots, I$), P_{ik} is the probability landowner k will choose land use i ($k = 1, \dots, K$), $E(A_k)$ is the expected acreage that will be used by sample owner k , M_k is the number of acres in the region represented by one acre of land in the sample tract held by owner k , and x_k is a vector of variables that determine the owner's land-use decision.

The statistic \hat{S}_i shows that aggregate land use can be predicted for hypothetical situations by developing an econometric model which would yield estimates of P_{ik} and $E(A_k)$ from given values of the land use determinants x_k . Since government incentives are legitimate elements of x_k , the model could be used to estimate how P_{ik} and $E(A_k)$ vary with proposed changes in government incentives. Aggregate acreage response to each change could then be determined by inserting the probability and expected acreage estimates into Equation (1): values for the expansion factor M_k would be available from the area sample frame. Predictions obtained for \hat{S}_i could then be compared to the estimated costs of the government incentives to assess the potential effectiveness of alternate programs.

ANALYTICAL APPROACH

For estimation purposes, reforestation investment may be viewed as a decision process in which the owners simultaneously choose a site treatment and the acreage to be treated. If the k th owner's selection from the I land-use choices is made to maximize some underlying value (for example, the expected profit or utility gained from owning forestland), one may hypothesize the following underlying selection criterion:

$$y_{ik}^* = F_i(x_k, \mu_{ik}) \quad i = 1, 2, \dots, I; \quad k = 1, 2, \dots, K \quad (2)$$

where y_{ik}^* is an unobserved or "latent" profit or utility measure. The vector $x_k \in R^m$ would include observed investment determinants (e.g., prices, costs, or incentives) and owner characteristics (e.g., income or occupation). The random variable $\mu_{ik} \in R^1$ is a measure of the unobserved factors affecting the k th owner's choice.

Although the profit or utility measure is unobserved, the choice of treatment made by the owner (e.g., planting, seeding) is observable. If the owner maximizes y_{ik}^* , the observed treatment choice by owner k may be represented by

$$y_k = i \text{ if } y_i^* > y_j^* \quad \forall j \neq i \quad j = 1, \dots, I. \quad (3)$$

Thus the maximization assumption is sufficient to relate the observed choice to the underlying latent measure of returns from the forestland.

The definition of y_{ik}^* allows some diversity in the landowner motive for holding forestland. This diversity is restricted, however, by the assumption that landowners who make the same choice have the same objective. Thus, for example,

owners choosing not to replant after harvest can hold forestland for reasons other than profit maximization, while owners that do replant can seek maximum profits from the production of timber. But all landowners choosing not to replant must use the same selection criterion. This "representative owner" assumption is necessary to obtain estimated results from a cross-sectional survey.

Acreage receiving treatment i by owner k may be expressed as:

$$A_{ik} = \begin{cases} G_i(x_k, \eta_{ik}) & \text{if } y_k = i \\ 0 & \text{otherwise} \end{cases} \quad (4)$$

where $G_i > 0$, and $\eta_{ik} \in R^1$ is a zero-mean random variable measuring unobserved determinants of the amount of acreage treated. Thus the representation of the landowner's choice by y_k allows a corresponding categorization of the treated acreage. If G_i is also linear in parameters, Equation (4) may be expressed as a censored regression model:

$$A_{ik} = \begin{cases} \beta'_i x_k + \eta_{ik} & \text{if } y_k = i \\ 0 & \text{otherwise.} \end{cases} \quad (5)$$

Here $\beta_i \in R^m$ is a parameter vector, $i = 1, 2, \dots, I$ and $k = 1, 2, \dots, K$.

AN ECONOMETRIC MODEL

The particular model used in the illustrative application has a dichotomous selection criterion. The owner decides either to leave the regeneration of the pinelands to nature ($i = 1$) or to actively invest in pine regeneration by planting, seeding or leaving seed trees during harvest ($i = I = 2$). The function representing this reforestation decision is also assumed to be linear in parameters, so that

$$y_k^* = \gamma' x_k + \mu_k \quad (6)$$

where $\gamma \in R^m$ is a vector of parameters. If, in addition, it is assumed that the variance-covariance matrix

$$\text{Cov}(\mu_k, \eta_{1k}, \eta_{2k}) = \begin{bmatrix} \sigma_{11} & \sigma_{12} & \sigma_{1\mu} \\ \sigma_{12} & \sigma_{22} & \sigma_{2\mu} \\ \sigma_{1\mu} & \sigma_{2\mu} & 1 \end{bmatrix} \quad (7)$$

is from a trivariate normal distribution, probit maximum likelihood techniques may be used to estimate the parameters in γ .

The expected acreage treated in this case by the NIPF owner can be consistently estimated by applying ordinary least squares to an equation derived from the expected acreage decision. Since

$$y_k = 1 \text{ if and only if } y_{1k}^* > y_{2k}^* \quad (8)$$

$$y_k = 2 \text{ if and only if } y_{1k}^* \leq y_{2k}^* \quad (9)$$

$E(A_k)$ may be defined as

$$\begin{aligned} E(A_k) &= E(A_k | y_k = 1) \text{Prob}(y_k = 1) + E(A_k | y_k = 2) \text{Prob}(y_k = 2) \\ &= \beta'_1 x_k (1 - \Phi_k) + \beta'_2 x_k \Phi_k + \phi_k (\sigma_{2\mu} - \sigma_{1\mu}) \\ &= \beta'_1 x_k + (\beta'_2 - \beta'_1) x_k \Phi_k + \phi_k (\sigma_{2\mu} - \sigma_{1\mu})^1 \end{aligned} \quad (10)$$

Equation (8) is the acreage response function for the naturally regenerated acreage, and Equation (9) is the corresponding function for the acreage that is planted, seeded, or left with seed trees. The derivation of this equation from equations similar to (8) and (9) is in Maddala (1983), pp. 223-228. $\Phi_k = \Phi(\gamma' x_k)$, the probability owner k will plant, seed, or leave seed trees, is a value from the standard normal cdf and $\phi_k = \phi(\gamma' x_k)$ is from the corresponding density function. Values for these variables can be obtained by substituting the estimated values of γ from the probit model. Equation (10) indicates which coefficients are significantly different between Equations (8) and (9). It allows the diversity of motive between landowner classes that previous studies have indicated to be important (Alig et al. 1990).

The error term of the regression model corresponding to Equation (10) is heteroscedastic. Maximum likelihood techniques would yield efficient parameter estimates for this model, but convergence of the likelihood function is often difficult to establish (Greene 1981). We were only able to obtain consistent estimates for the β parameters in the example, but corrected the variance-covariance matrices of these estimates for heteroscedasticity (White 1978).

Given the estimated parameters, acreage receiving treatment i can be predicted by using Equation (1). The component $E(A_k)$ would be replaced in this equation by an estimated value from Equation (10). The probability $P_{2k} = \Phi_k(\gamma' x_k)$ would be estimated from the probit results and the standard normal cdf. The probability P_{1k} would be estimated as $1 - P_{2k}$. Thus, the model defined by Equations (6)-(10) can provide the simultaneously determined values needed to estimate \hat{S}_i .

DATA AND VARIABLE DEFINITION

Most of the data used in the illustrative application comes from a South-wide area frame survey of NIPF owners who harvested timber between January 1, 1971, and May 15, 1981 (Fecso et al. 1982). This survey is restricted to owners who did not convert their land to a nonforest use after harvest. It identifies NIPF owner pine regeneration decisions, measures the number of acres involved, and provides data on landowner attributes, intentions and attitudes. Because the survey is from an area sample frame, the expansion factors needed to aggregate model results to regional acreage totals are available. The frame also creates the direct correspondence between owner and acreage variables needed to simultaneously estimate landowner and acreage response.

Royer (1987) used this data set to estimate the probability that a representative NIPF owner would plant, seed or leave seed trees. Since the Fecso et al. data set does not contain stumpage prices or reforestation costs, Royer introduced data

¹ The term including the covariances in Equation (10) results from the conditional nature of the acreage in each land use.

for these investment determinants from other sources. This illustrative application uses the Royer data set. Specific definitions of the variables used in the analysis are given in Table 1.

PARAMETER ESTIMATES FOR THE REFORESTATION DECISION EQUATION

Parameter estimates for the reforestation decision Equation (6) are given in Table 2. The selection variable for this probit estimation is CHOICE (cf. Table 1), which is represented as y_k in model (6)–(10).

Inspection of Table 2 shows that the signs of the estimated parameters are as expected. Both cost and price significantly affect the probability estimates, and income and information serve as effective constraints on the owner's reinvestment choice. Owners with higher incomes and more information from professional foresters are more likely to plant, seed, or leave seed trees. Income also interacts with prices and with farmer occupation in determining the owner's choice. Farmers are less likely to plant, seed, or leave seed trees during harvest.

The reforestation decision equation's ability to predict observed choices is good. The Morrison-Goldberger Coefficient of Determination is 0.58, a relatively high value for this particular statistic (Maddala 1983). Also, some 84% (57 out of 68) of the owners choosing to actively invest are predicted to do so by the model. Only 8% (12 out of 159) of the owners choosing not to plant, seed, or leave seed trees are incorrectly predicted. Overall, the equation correctly predicts the choices of 204 of the 227 owners in the subsample of observations with no missing values. This is approximately 90% of the total choices in the subsample.

TABLE 1.

Variable descriptions for the pineland reforestation models.

Variable name	Variable description
CHOICE (Y)	1 if owner planted seedlings, seeded site, or left seed trees, 0 otherwise.
ACRE (A)	Acres of timberland harvested in sample segment during 1971–1980.
NETCOST	Subsidized cost of reforestation in dollars per acre, 1983. Full costs used for owners with no knowledge of cost sharing.
PUBCOST	Subsidized cost of reforestation in dollars per acre if the owner receives public forester assistance, 0 otherwise.
INCOME	1980 annual household income, thousands of dollars.
YFARM	Annual income if owner is a farmer, 0 otherwise.
YFOREST	Annual income if owner is located in a sample segment described as forestland, 0 otherwise.
PWP	Pulpwood price: 6 yr average for 35 <i>Timber Mart South</i> regions, \$ per cord.
YPWP	Cross-product: income and pulpwood price.
STP	Sawtimber price: 6 yr average for 35 <i>Timber Mart South</i> regions, \$ per mbf.
YSTP	Cross-product: income and sawtimber price.
PUBFOR	1 if owner used services of a public forester during 1971–1980, 0 otherwise.
CONFOR	1 if owner used services of a consulting forester during 1971–1980, 0 otherwise.
INDFOR	1 if owner used services of an industrial forester during 1971–1980, 0 otherwise.
SIZE	Acres of forestland owned or co-owned by landowner, 1980.
INHERIT	1 if harvested site was inherited, 0 otherwise.

TABLE 2.

Parameter estimates and sample statistics for model used to predict probability of an active investment.

Variable name	Parameter estimate (standard error)	T-Ratio (significance level)	Sample mean (standard deviation)
Constant	-1.8820 (1.285)	-1.47 (14%)	1.0 (0.0)
NETCOST	-0.02519 (0.00452)	-5.58 (<1%)	77.36 (41.98)
INCOME	0.07869 (0.03827)	2.06 (4%)	25.45 (17.65)
YFARM	-0.02272 (0.00988)	-2.30 (2%)	7.35 (16.65)
PWP	-0.11221 (0.06278)	-1.79 (7%)	11.76 (4.87)
YPWP	0.00637 (0.00220)	2.90 (<1%)	307.68 (281.45)
STP	0.02694 (0.01078)	2.50 (1%)	125.72 (27.08)
YSTP	-0.00112 (0.00040)	-2.80 (<1%)	3113.6 (2221.3)
PUBFOR	1.23754 (0.31910)	3.88 (<1%)	0.216 (0.412)
CONFOR	1.37384 (0.51900)	2.65 (1%)	0.093 (0.290)
INDFOR	0.84087 (0.48670)	1.73 (8%)	0.062 (0.241)

Likelihood ratio test: Chi-squared = 153.62 (significance level: <1%) Morrison-Goldberger $R = 0.58$.

PARAMETER ESTIMATES FOR THE EXPECTED ACREAGE EQUATION

Estimates of the acreage that would be reforested if an owner chooses to plant seedlings, seed the site, or leave seed trees are obtained from a subsample of 224 owners.² Results are given in Table 3, where parameter estimates for a model based on Equation (10) are given. Private reforestation costs, the price of sawtimber stumpage, and owner income are significant determinants of the number of acres planted, seeded, or left with seed trees. Whether forestland was inherited or purchased also is significant: NIPF owners who inherited land invested in larger acreages when regenerating pines. The lower incomes observed in localities with relatively large proportions of forested land (as measured by YFOREST) resulted in smaller acreages receiving landowner regeneration investments.

Only the constant term, SIZE, INHERIT, and the cross-product between reforestation costs and public forester assistance (PUBCOST) explain the quantity of harvested acreage that is not planted, seeded, or left with seed trees [cf. Equation (8)]. This result might be a function of data availability, since the variables in the data set are most relevant to the decision to invest in timber production. The standard error incurred using this model is 67.3 ac, compared to an initial standard error of 80.2 ac.

² This subsample omits three additional observations with missing acreage values.

TABLE 3.

Parameter estimates and sample statistics for model used to estimate reforested acreage.

Variable name	Parameter estimate (standard error)	t = statistic (significance level)	Sample mean (standard deviation)
Constant	49.611 (9.004)	5.51 (<1%)	1.0 (0.0)
SIZE	0.09499 (0.03197)	2.97 (<1%)	230.49 (176.18)
INHERIT	-26.485 (9.7717)	-2.71 (1%)	0.451 (0.499)
PUBCOST	0.66569 (0.40092)	1.66 (10%)	7.989 (18.020)
PHI ^a	-165.775 (64.416)	-2.57 (1%)	0.303 (0.353)
PHI*NETCOST	-1.3859 (0.71199)	-1.95 (5%)	11.819 (13.189)
PHI*INHERIT	73.287 (34.720)	2.11 (3%)	0.127 (0.269)
PHI*INCOME	3.4659 (1.0334)	3.35 (<1%)	9.675 (15.026)
PHI*STP	1.0350 (0.41197)	2.51 (1%)	36.329 (43.239)
PHI*YFOREST	-2.4314 (0.77766)	-3.13 (<1%)	4.538 (11.109)
DENSITY ^b	-23.330 (45.128)	-0.52 (60%)	0.153 (0.142)

Mean of Dependent Variable = 64.15. Adjusted Coefficient of Determination = 0.30. Standard Error of Regression = 67.35. Number of Observations = 224.

^a PHI = $\Phi(\gamma'x_k)$, see Equation (10).

^b DENSITY = $\phi(\gamma'x_k)$, see Equation (10).

COST-SHARING AS A PINE REGENERATION POLICY

The question of whether or not to subsidize reforestation of harvested pineland in the South is a policy issue of importance both to federal and state governments. One aspect of this issue is the effectiveness of cost-sharing in encouraging reforestation. Here acreages that would have been planted, seeded, or left with seed trees in 1971-1981 are estimated for each of several hypothesized cost-sharing alternatives. Elasticities of owner and acreage response are also defined and calculated for the alternative policies.³

Five hypothetical alternatives are analyzed. The first examines what would have happened to pine regeneration in the South if the federal and state cost-

³ The term "elasticity" refers to the percentage change in a dependent variable (e.g., probability of reforestation, acres reforested) associated with a 1% change in an independent variable (e.g., net cost of reforestation). When an elasticity exceeds an absolute value of one, the dependent variable is said to be elastic with respect to the independent variable. Elasticity definitions for these responses are given below.

sharing programs had not existed during the 1971-1981 survey period. Restrictions on funding that existed during this period are removed in the second scenario, which assumes that all NIPF owners who conducted a final harvest on pineland during the survey period participated in the cost-share programs. In actuality, the programs were restricted to a subset of these owners. The third scenario builds on the second by assuming that all NIPF owners who did a final cut received cost sharing during the period and that the government programs paid for 80% of the total costs. In actuality, the government programs paid an average of 69% of the costs. In the fourth scenario, all NIPF owners with final harvests receive cost sharing but at a rate of only 30% of the total costs. The fifth scenario simulates the situation that would have held if the owners who actually received cost sharing during the survey period had been offered 30% instead of 69% of their reforestation costs. Other alternatives are possible, but these will illustrate how the proposed method can be used to predict owner and acreage response to proposed changes in cost-sharing programs.

Criteria used to assess the potential effectiveness of cost sharing in the policy simulations include: (1) the expected probability that a NIPF owner who harvested would have planted, seeded, or left seed trees, (2) the expected acreage that would have been reforested by NIPF owners who harvested and who chose to invest in these reforestation methods, (3) the acreage that would have been planted, seeded, or left with seed trees, divided by the total number of NIPF owners who harvested during the period, (4) the total January 1971-March 1981 acreage in NIPF ownership that would have been planted, seeded, or left with seed trees in the South and, (5) the total cost to the federal and state governments of subsidizing this reforestation.

ELASTICITY DEFINITIONS

Three elasticities will also be used to compare the hypothesized policies. These include (1) the mean cost elasticity of the probability of NIPF owner investment in pine regeneration, (2) the mean cost elasticity of acreage response for a typical southern NIPF owner, and (3) the mean cost elasticity of total acreage response in the South. These mean cost elasticities are derived as follows:

1. E_{pk} , the cost elasticity of the probability that owner k will plant, seed, or leave seed trees is defined as:

$$E_{pk} = \frac{\partial P_{2k}}{\partial x_{1k}} \frac{x_{1k}}{P_{2k}} \quad (11)$$

where P_{2k} is the probability owner k will invest in pine regeneration, and x_{1k} is the per acre net cost of regeneration to the owner (NETCOST). This elasticity is computed from the sample data as $\bar{E}_{pk} = -0.02519 \cdot \text{DENSITY} \cdot \text{NETCOST}/\text{PHI}$. The mean cost elasticity of probability is obtained as a simple average:

$$E_p = \frac{1}{K} \sum_{k=1}^K E_{pk} \quad (12)$$

2. E_{ak} , the cost elasticity of acreage response for owner k , is defined as:

$$E_{ak} = \frac{\partial E(A_k)}{\partial x_{1k}} \frac{x_{1k}}{E(A_k)} \quad (13)$$

where

$$E(A_k) = \beta_2'x_k + (\beta_2 - \beta_1)' \Phi_k x_k + \phi_k(\sigma_{2\mu} - \sigma_{1\mu}), \text{ and } x_{1k}$$

is the variable NETCOST. The elasticity is estimated as:

$$\hat{E}_{ak} = [0.665687 \cdot \text{PUBFOR} - 1.38594(1 + \hat{E}_{pk}) \cdot \text{PHI}] \text{NETCOST} / \hat{A}_k \quad (14)$$

where \hat{A}_k is the estimate of $E(A_k)$. As before, the mean cost elasticity of the owner's acreage response (E_a) is found by averaging the individual elasticities over the sample of owners.

3. E_{th} , the cost elasticity of total acreage response in the South, is derived from Equation (1). This elasticity may be defined as:

$$E_{th} = \frac{\partial \hat{S}_2}{\partial x_{1k}} \frac{x_{1k}}{\hat{S}_2} \quad (15)$$

where, as before, x_{1k} is the per acre net cost of regeneration to the owner. It is straightforward to show that $E_{th} = E_{pk} + E_{ak}$, so

$$E_t = \sum_k \left[\frac{E_{pk} + E_{ak}}{K} \right] = E_p + E_a. \quad (16)$$

It is clear from the computation of E_{pk} that the cost elasticity of the probability that the owner will plant, seed, or leave seed trees is negative. Thus an increase in owner costs will reduce the probability that an owner will invest in the regeneration of pines. However, the cost elasticity of acreage response for the average owner may be either negative or positive, depending on whether or not the positive effect of public forester assistance outweighs the negative effect of a cost increase. As Equation (14) shows, the acreage response includes both the effect of a cost increase on the acreage reforested and the effect of a cost increase on the probability that an owner will plant, seed, or leave seed trees. Since signs can vary over owners, the mean cost elasticity of total acreage response could be positive; but it is unlikely that this will occur.

COMPARISON OF TOTAL ACREAGE ESTIMATES

To obtain estimates for the total acreage receiving regeneration investments during the 1971–1981 period, missing income values are interpolated in the sample data. This is done using a regression of income on other survey variables. Missing inheritance values are set equal to 0.5. These interpolations yield a useable subsample of 248 observations, three less than the total sample of 251 owners.⁴ Estimates of expected probabilities that NIPF owners will plant, seed, or leave seed trees are then obtained by applying the probability model of Table 2 to the sample of 248. Estimates of sample acreages reforested are obtained from the acreage model of Table 3. Equation (1) is used to obtain total acreage estimates for the region.

Fecso et al. state that 1,269,000 ac of NIPF lands were planted, seeded, or left with seed trees in the South during the 1971–1981 period. The survey data set gives 1,076,911 ac as the total for this period, some 15% less than the cited

⁴ Three observations are omitted because of missing values for acreage and for the expansion factor relating sampled acreage to the total acreage in the region.

figure. The total acreage predicted by applying the estimated model to the sample of 248 observations is 1,113,074 acres, a value that is 3% higher than the sample total and 12% less than the cited figure. Much of the difference between the sample total and the predicted value is due to the interpolation of the missing income figures.

The total reforested acreage reported by Fecso et al. differs substantially from that reported in other USDA Forest Service studies (e.g., USDA Forest Service 1981, 1988). For example, the 1988 USDA Forest Service study reports that 2,899,000 ac were planted or directly seeded on NIPF lands in the South in the fiscal years 1971 through 1981 (Table 2.11, p. 290). These higher estimates of reforestation are derived from nursery totals for seedlings and seed instead of from direct surveys of NIPF owners. They depend on assumed planting rates, and they are not adjusted for planting on previously planted sites, for mortality during planting, or for changes in site use after the stand is established (Williston 1980). In each case, an adjustment would decrease the acreage estimate.

In contrast, the reforestation acreage figure derived from the Fecso et al. survey may be low due to the difficulty of identifying and sampling owners who harvested early in the survey period. There is no clear way to reconcile the difference between acreage estimates and no attempt is made to do so in the following results. The survey data are used to illustrate the proposed method of analyzing potential government land-use programs.

The values of the probability, acreage, and elasticity measures computed from the sample of 248 observations for the earlier outlined cost-sharing alternatives are reported in Table 4. The base alternative given in this table gives the corresponding estimates for the situation as it actually existed in the survey period. Since descriptive values are available for this period, this alternative may be used to review how well the model predicts values from the Fecso et al. data. It also provides a base against which to compare the results from the other alternatives.

BASE ALTERNATIVE: OBSERVED SITUATION

Thirty-one percent of the surveyed owners planted, seeded, or left seed trees. This compares to an estimated probability of 0.30. An average of 65 ac was reforested by these owners. The same average was estimated using the model. Total sample acreage receiving reforestation investment, when divided by all sample owners who harvested, equaled 27 ac, a value that was also correctly estimated by the model. As noted earlier, the model predicts total acreages planted, seeded, or left with seed trees in the South to be 1.113 million ac. This is some 3% greater than the 1.078 million ac obtained from summing up the reported acreages in the sample of 248. Thus the probability estimate falls slightly below the descriptive value, while the total acreage prediction is slightly above.

Estimated probabilities that an owner planted, seeded, or left seed trees are elastic at the level of cost-sharing observed during the survey period (Table 4). A 1% decrease in the owner's cost-share at this level of investing in pine regeneration would have invoked more than a 4% increase in the owner's probability of making such an investment. In contrast, a 1% increase in the government subsidy would have stimulated only three-tenths of a percent increase in the acreage treated by the owner who invests. Total acreage response for the region would

TABLE 4.

Estimates of reforestation probabilities, reforested acreages, and elasticities resulting from different cost-sharing policy alternatives for 1971-1981 period.

Estimate	Policy alternative ^a					
	Base	1	2	3	4	5
Probability owner will reforest (in percent)	30.3	10.3	49.5	58.4	22.4	17.3
Average acreage receiving investment (in acres)	65.1	64.9	64.0	72.2	56.8	60.1
Average acreage reforested by all owners (in acres)	27.1	7.7	37.7	48.1	15.1	13.1
Total acreage reforested ^b in South (1971-81) (in mil. acres)	1.113	0.316	1.563	1.987	0.619	0.532
Total cost to government (in mil. dollars)	122.3	0.0	216.3	246.0	50.9	92.3
Elasticity of investment decision	-4.38	-6.72	-0.77	-0.040	-3.30	-5.35
Elasticity of acreage response: representative owner	0.30	0.40	-0.26	-0.68	0.22	0.40
Elasticity of acreage response: total region	-4.08	-6.32	-1.03	-1.08	-3.08	-4.95

^a Policy alternatives are: (1) remove cost sharing programs; (2) extend subsidies to all NIPF owners who harvested during period; (3) increase the subsidy rate to 80% and extend to all NIPF owners; (4) extend cost-sharing to all owners, but reduce rate to 30%; (5) restrict cost-sharing to owners receiving subsidy during period and reduce rate to 30%.

^b Estimated from Fecso et al. (1982) data for 1971-81.

have been elastic because of the number of owners who would have shifted to actively investing in pine regeneration. A 1% increase in the 69% average cost share granted during the survey period would have resulted in an estimated increase of 45.4 M ac in treated pine land.

POLICY ALTERNATIVE 1: CANCEL COST SUBSIDIZATION

Removal of the cost subsidy during the 1971-1981 period would have had only a small effect on the estimated acreage treated by an owner who decided to invest in pine regeneration. However, it would have had a large effect on the number of owners choosing to invest: the estimated probability that a NIPF owner would have planted, seeded, or left seed trees drops from 0.30 to 0.10. As a consequence, the estimate of the total acreage receiving these investments decreases from 1.113 million ac to 316 M ac. This suggests cost-sharing stimulated over 70% of the NIPF reforestation investment observed in the South during the survey period.

POLICY ALTERNATIVE 2: SUBSIDIZE ALL OWNERS WHO HARVEST

Model estimates indicate that if cost-sharing had been available to all owners who harvested during the survey period, total acreage planted, seeded, or left with seed trees would have increased to 1.563 million ac. This is some 40% above the base level of 1.113 million ac. As before, the change in estimated total acreage is due primarily to an increased probability that the NIPF owner would have chosen to invest in pine regeneration: this estimated probability increases from 0.30 to approximately 0.50. As the proportion of owners estimated to invest increases, however, the cost elasticities fall. When 50% of the NIPF owners are estimated to reforest using seedlings, seed, or seed trees, a 1% decrease in the owner's cost-share rate would result in only an 0.8% increase in the probability of an owner choosing to invest in regeneration. Even so, the estimated cost elasticity of total acreage would remain above 1, primarily because the increase in public subsidy rate would have stimulated a significant increase in the amount of acreage treated by the NIPF investor.

POLICY ALTERNATIVE 3: INCREASE COST SUBSIDIZATION RATE

The offsetting role of the amount of acreage treated is more apparent in policy alternative 3, which is alternative 2 plus an 11% increase in the subsidy rate. In this case, the cost elasticity of total acreage response becomes slightly more elastic, even though the absolute elasticity of the estimated probability that an owner chooses to plant, seed, or leave seed trees falls to 0.04. Thus, once free accessibility to the program is assured, an 11% increase in the cost subsidy would have encouraged few additional owners to invest in active regeneration practices. But it would have encouraged the owners who were already planting, seeding, or leaving seed trees to have increased acreages treated. This estimated acreage increase would have been enough to keep the total acreage response elastic. The results of Table 4 suggest that, given an 80% public cost-share rate, a 1% rate increase would have generated a 1.08% increase in the total NIPF acreage planted with seedlings, seeded, or left with seed trees in the South.

POLICY ALTERNATIVES 4 AND 5: DECREASE COST SUBSIDIZATION RATE

Policy alternatives 4 and 5 explore the consequences of reducing the government's rate of cost sharing to 30% of total costs, a tactic that would have essentially reversed the relative shares of the total cost borne by the public and private investor during the survey period. If free accessibility to the subsidization program had been granted to all NIPF owners who harvested in this period, total pine land acreage planted, seeded, or left with seed trees would have fallen from 1.113 million ac to 617 M ac. If accessibility remained at survey period levels, the reduction would have been to 532 M ac. The expected percentage of owners who would have planted, seeded, or left seed trees also would have decreased from 30% to 22 and 17%, respectively. At these levels, a 1% increase in the government subsidy rate would have increased the number of owners adopting these practices by 3.3 and 5.4%, respectively. Aggregate acreage planted, seeded, or left with seed trees in the region would have increased by 3 and 5%.

SUMMARY AND CONCLUSIONS

Several studies (Boyd 1984, Hyberg 1986, Royer 1987) predict the probability that a southern NIPF owner will choose to invest in pine regeneration on harvested land. Each of these show knowledge of cost-sharing to be an important determinant of the investment decision, but none take the additional step of estimating the total acreage that would be treated as a result of a cost-share program. Total acreages receiving regeneration investments in a given region have been estimated from models using aggregate land use data (Brooks 1985). Estimates from these studies capture the effect of cost-sharing, but only for the landowners that invested during the data period. Measurement of the effectiveness of new or untried incentives in changing the total acreage receiving regeneration investments requires simultaneous estimation of the probability that owners will invest and of the acreage that will receive this investment.

The empirical results of the paper are restricted by data availability to a historical analysis of what might have been. Current results would depend on obtaining a current area frame sample. Since such samples are expensive, the proposed method of analysis is practical only for policies involving potentially large government expenditures and affecting potentially large amounts of land. To date, however, comparable results have not been obtained from other less expensive studies of forest land use.

There is considerable debate surrounding the effectiveness of cost-sharing programs in the South (Alig et al. 1990). Part of this debate may arise because completed studies of cost-sharing do not explicitly consider the land input aggregation problem. Results developed from these studies are based on samples of NIPF owners drawn without regard to land characteristics. These samples may also include owners with differing land use motives, and reported cost-share findings may be influenced by the mix of motive in the sample.

Use of an area frame sample to control for the heterogeneity of land allows the analysis of the data to be focused on landowner behavior. Use of a discrete-continuous choice model allows for some diversity in owner motives for holding forestland. Simultaneous estimation of behavior and acreage response provides a way to assess the effectiveness of proposed land-use policies before they are implemented.

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APPENDIX: AGGREGATION OF DATA FROM AN AREA-BASED SAMPLE

Although the population of the South-wide reforestation survey is defined in terms of owners, the sample was determined by subdividing the total land area in the South into small blocks or segments and then selecting a probability sample from these segments. All tracts from within the sample segment harvested during the designated period were then identified, and the owner or co-owner of each identified tract was surveyed. Owner responses consequently make up the observations of the sample, but aggregation of the responses is in terms of the number of acres in the South represented by each sample observation.

This type of aggregation is done as follows (Fecso et al. 1982). Let i represent type of post-harvest treatment, with $i = 1$ representing the option to let the site regenerate without planting, seeding, or leaving seed trees. Assign $N_k(i)$ the value of 1 if sample observation k is for an owner in class i , and set $N_k(i)$ equal to 0 otherwise. Let $A_k > 0$ be the acreage treated by the k th owner in the sample of K owners and M_k be the expansion factor estimated from the area probability sample. When multiplied by A_k , this expansion factor yields the total acreage in the South represented by observation k . The total acreage in the South receiving treatment i can then be estimated as:

$$S_i = \sum_{k=1}^K N_k(i) A_k M_k \quad (\text{A.1})$$

Note that the corresponding population statistic would have K equal to the total number of NIPF owners who used treatment i in the designated period and M_k equal to one for all k .

If we are to estimate acreages under conditions different from those of the sample period, we need to convert the descriptive Equation (A.1) into an inferential statistic. Such a statistic would evolve naturally if the survey could be repeated for T mutually independent trials. Then the average total acreage receiving treatment i could be expressed as:

$$\hat{S}_i = \sum_{k=1}^K \left(\sum_{t=1}^T \frac{N_{kt}(i, X_{kt})}{T} \frac{A_{kt}(X_{kt})}{T} \right) M_k \quad (\text{A.2})$$

where X_{kt} is a vector of investment factors applying to owner k in trial t , $N_{kt}(i, X_{kt})$ is the value of $N_k(i)$ in the t th trial and $A_{kt}(X_{kt})$ is the acreage individual k chooses to treat in trial t . Equation (A.2) may be rewritten as:

$$\hat{S}_i = \sum_{k=1}^K P_{ik} E(A_k) M_k \quad (\text{A.3})$$

where P_{ik} is the frequency or probability that individual k will choose alternative i and

$$E(A_k) = \frac{1}{T} \sum_t A_{kt}$$

Equation (A.3) suggests the development of an econometric model that simultaneously estimates P_{ik} and $E(A_k)$ as a function of the set of vectors X_{kt} . Calibration of such a model will depend on a representative owner hypothesis, since repeated trials are not available ($T = 1$).

Principal Components Regression to Mitigate the Effects of Multicollinearity

BERNARD J. MORZUCH
GREGORY A. RUARK

ABSTRACT. One consequence of multicollinearity among the structural independent variables of a regression model is that variables are frequently deleted as a means of proceeding with sensible hypothesis tests. Principal components regression has the advantage of avoiding model specification error due to variable deletion. The technique works as follows: the independent variables are orthogonalized into their principal components; components with low information content are deleted; the model is estimated by ordinary least squares; then the principal component estimators are converted into coefficients in the original parameter space, where a judgement about their contribution is made via an F-test.

An example using tree growth data is presented to demonstrate the merits of principal components regression over variable deletion. Results indicate that "correct" structural specification does not have to be compromised through variable deletion when collinearity is present. This obviously has implications for large-scaled regression models, in which an increased number of independent variables in the specification may promote a level of collinearity that is not conducive to making statistical inferences. Analytical methods like principal components, that adjust for the effects of collinearity on the variable selection process, are merited. *FOR. SCI.* 37(1):191-199.

ADDITIONAL KEY WORDS. Restrictions, orthogonality, eigenvectors, sequential deletion.

IN APPLIED FORESTRY WORK, more often than not the researcher has access to data that are gotten from some external source, i.e., passively generated rather than being part of an experimental design. Frequently, the researcher desires to analyze the structural relationship among variables and chooses regression analysis as the vehicle for exploring issues relating to model structure. A problem frequently encountered with passively generated data is collinearity among the structural independent variables of the regression model itself. Applied researchers frequently confront this problem by resorting to data mining techniques as a means of conducting sensible hypothesis tests. This "solution," however, often turns out to be just as bad from a statistical point of view as the problem itself. Such techniques fall into the categories of stepwise regression or variable elimination. While they can serve a purpose, they frequently are over-used or misused (Freund 1974, Freund and Debertin 1975).

Basically, eliminating a variable from a model amounts to placing a restriction of zero on that variable's regression coefficient. Imposing such restrictions, especially in the context of collinearity, *always* reduces the variances of the remaining coefficients—a most attractive outcome with respect to the performance of hypothesis tests for the regression coefficients. However, eliminating a variable that

EFFECT OF SOIL FUMIGATION IN THE NURSERY ON GROWTH OF LOBLOLLY PINE SEEDLINGS AND CONTROL OF WEEDS

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Methyl bromide and Vapam as general soil fumigants for the control of fungi, nematodes, and weeds have been widely tested in forest nurseries (Briscoe and Strickland, 1956; Clifford, 1951; Foster, 1956; Henry, 1951; Hill, 1955; Stoeckeler, 1951; Wycoff, 1952). The excellent and consistent results obtained with methyl bromide to control weeds and increase total plantable seedlings make it probable that this fumigant would be in wider use were it not for the large amount of hand labor involved. The limited area that can be fumigated daily is also a serious drawback, since the soil is not warm enough for fumigation until planting time has almost arrived, and bad weather may prevent treatment.

Water-sealed Vapam has also been widely tested in forest nursery soils, but it has not been uniformly effective in controlling weeds and soil-borne diseases. For this reason, it has not been used more widely in forest tree nurseries.

In 1959, a study was undertaken at the Little River Nursery near Goldsboro, N. C., to compare the effectiveness of various formulations and techniques of applying methyl bromide and Vapam in controlling weeds and increasing seedling growth. In addition, several combinations of Eptam, a herbicide, and Nemagon, a nematocide, were also tested. These materials were included since they would be much cheaper to use than the general-purpose fumigants for certain specific objectives. For the most part, the materials tested had been used before and are commercially available. The major purpose of the study was to compare known effective treatments for the problems existing at the Little River Nursery. The results of the study, however, may be applicable to other southern forest nurseries or may serve as guides for future tests in other areas.

Only one material, Brozone, had not been used previously on forest nurseries. In California, this material has been effectively used for the control of weeds, nematodes, and soil-borne fungi at rates as low as 150 pounds actual methyl bromide per acre (Sher et al., 1958; Thomason, 1959; Wilhelm et al., 1958; Wilhelm et al., 1959). This material contains, by volume, 50 percent methyl bromide and 50 percent of a petroleum carrier. Brozone is injected into the soil with chisel applicators and then the soil is covered with polyethylene covers.

Procedure

The tests were laid out in a randomized block design with three replications of each treatment. Each plot was 60 by 4 feet. Weed ratings were made 6 and 12 weeks after planting, on a rating system of 0 to 10, with 0 indicating complete control and 10 no control. All the plots were weeded by hand following the first rating, since the weeds in some plots were interfering with normal seedling growth. After the second rating, the plots were weeded by applications of mineral spirits or by hand.

At digging time, all the seedlings in a 4- by 4-foot area in the center of each plot were lifted and graded according to Wakeley's morphological grades (Wakeley, 1954). The average weight per seedling was taken by averaging the weights of every 25th plantable seedling selected during the grading operation.

The following treatments were included in the study:

1. Methyl bromide

- A. as the standard treatment¹ of 1-pound per 150 square feet (300 pounds per acre) released under a 4-mil polyethylene cover.

¹The chemicals used in this study were contributed by the following companies: Vapam and Eptam, Stauffer Chemical Co.; Brozone, Hendrix-Barnhill Co., Greenville, N. C.; vaporized methyl bromide, Dow Chemical Co. Mention of any chemical company or product does not imply endorsement by the U. S. Department of Agriculture.

B. vaporized and released at the rate of 300 pounds per acre under a 2-mil polyethylene cover put down with an automatic covering device made by Dow Chemical Company.

C. as Brozone at the rate of 175 pounds per acre actual methyl bromide, injected into the soil and covered with a 2-mil polyethylene cover or left uncovered.

2. Vapam

A. at 50 and 100 gallons per acre drenched into the soil with 1300 gallons water.

B. at 50 gallons per acre drenched into the soil and covered for 2 days with a 2-mil polyethylene cover.

3. Eptam

A. in liquid form at the rate of 6 pounds active ingredient (1 gallon) in 75 gallons water per acre applied to the soil surface and disked in.

B. as in A with an additional 6 pounds in 75 gallons water sprayed on seedlings 6 weeks later.

C. as in A plus 50 gallons per acre Vapam.

D. as in A plus 1 gallon per acre (active ingredient) Nemagon.

E. in the granular form at the rate of 6 pounds per acre active ingredient applied on the surface and disked in.

4. Nemagon

A. in the granular form at the rate of 1 gallon per acre active ingredient applied to soil surface and disked in.

5. Check--no treatment.

All treatments were applied at least 2 weeks before planting. The area of the Little River Nursery, where the tests were conducted, is classified as a Wickham fine sandy loam soil.

Results

Considering all criteria measured in the study, the covered Vapam, covered Brozone, standard methyl bromide, and vaporized methyl bromide treatments were significantly superior to no treatment (table 1). The treatment with noncovered Brozone resulted in a significant increase in the number of plantable seedlings. However, seedlings were much smaller than those in the above treatments and weed control was inadequate.

The water-sealed Vapam treatments neither increased seedling size nor lowered weed rating. The fact that this material gave excellent results in all respects when sealed with a polyethylene cover is good evidence that the poor results obtained in the past with this material are due to failure to get an adequate seal with water.

Weed control with both the liquid and granular formulations of Eptam was excellent through 12 weeks but this material did not significantly increase seedling growth.

Nemagon only slightly increased seedling size, indicating that nematodes are not a major factor at this nursery. Weed ratings were significantly increased with this material at the 6-week rating period and were higher than the check at the 12-week rating.

TABLE 1.--Effect of various soil fumigants on growth of loblolly pine seedlings and weed control

Chemical	Rate per acre	Seedlings per square foot		Average seedling weight	Weed rating	
		No. 1	Plantable		6 wks.	12 wks.
Methyl Bromide (standard).....	300 lbs.	Number 1.7**	Number 42.1**	Grams 10.2**	1.3**	1.7*
Methyl Bromide (vaporized).....	300 lbs.	0.9**	31.3*	10.1**	2.7*	2.0*
Brozone (covered).....	175 lbs.	2.8**	32.6*	12.8**	1.3*	1.7*
Brozone (not covered)...	175 lbs.	0.1	30.3*	5.9	3.3	4.0
Brozone (not covered)...	350 lbs.	0.0	32.0*	6.5	3.0	3.7
Brozone (not covered)...	525 lbs.	0.2	31.3*	7.7*	3.0	3.3
Vapam (water sealed)...	50 gal.	0.0	25.1	6.9	5.0	4.3
Vapam (water sealed)...	100 gal.	0.0	16.3	5.7	5.3	6.0
Vapam (covered).....	50 gal.	1.5**	37.8**	9.9**	1.0**	1.0**
Granular Eptam.....	6 lbs.	0.1	32.1	7.3	1.3*	2.0*
Liquid Eptam.....	6 lbs.	0.0	28.5	7.1	1.7**	5.3
Liquid Eptam)..... + Liquid Eptam).....	6 lbs. 6 lbs.	0.0	26.2	6.2	2.7*	2.0*
Liquid Eptam)..... + Vapam).....	6 lbs. 50 gal.	0.0	20.5	6.9	1.0**	2.3
Liquid Eptam)..... + Nemagon).....	6 lbs. 1 gal.	0.0	21.7	5.5	2.3*	3.7
Nemagon.....	1 gal.	0.1	24.3	7.3	9.0**	7.0
Check.....	--	0.0	17.0	6.2	5.3	5.0
LSD, 5 percent.....		0.5	11.8	1.5	2.6	3.1
LSD, 1 percent.....		0.7	15.9	2.1	3.5	4.1

*Denotes significance at the 5 percent level.

**Denotes significance at the 1 percent level.

Discussion

From the standpoint of a general soil fumigant, covered Brozone appears to be very promising. At present this material is available only by contract application by a Dow Chemical Company distributor. Based on contract prices for over 100 acres of nursery soil to be fumigated in North Carolina and South Carolina, the cost of fumigation with Brozone is about equal to or even less than the cost for the standard application of methyl bromide with 1-pound cans and 100- by 20-foot covers. On the basis of the present studies and on inspection of tobacco plant beds treated with Brozone, an application rate of about 200 pounds per acre actual methyl bromide will probably be adequate for most nurseries located on light soils. Further studies of application rates on different soil types are needed.

Since the application of Brozone is highly mechanized, up to 6 acres per day can be fumigated, as compared with approximately 1 acre by the standard method. This is very important when the time available for fumigation is limited.

Vapam, at the rate of 50 gallons per acre and covered with polyethylene, also looks promising. At this rate, the treatment is comparable in cost to methyl bromide and it may cost less if application techniques can be improved by using covers several hundred feet long and sealing the edges of the covers with tractor equipment.

The vaporized methyl bromide was as effective as the other methyl bromide treatments but unless the cover-laying device is modified to use 18- to 20-foot covers instead of the present 6- to 9-foot covers, this method appears uneconomical for broadcast fumigation because of the high percentage of overlap between covers. For single-bed treatment, however, the method would be excellent.

From the standpoint of weed control alone, Eptam gave excellent results up to 12 weeks after planting. Some weed control was obtained up to digging time, but the treatment could not be considered effective over the entire growing season. Inasmuch as the first 8 to 12 weeks is the most critical period from the standpoint of mechanical damage from hand weeding, and the cost of the material and application at the 6-pound rate is only about 35 dollars per acre, Eptam could be a very economical treatment.

No adverse effects on the seedlings were noted in any of the treatments. It should be noted here, however, that Eptam at 5- and 10-pound rates has caused some stunting of seedlings in a Georgia nursery. This may have been due to the heavier soil on which that study was conducted, and is a factor to consider when determining the length of time between application and planting.

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EFFECT OF CRAIG MYLONE HERBICIDE ON THE GROWTH OF WHITE SPRUCE SEEDLINGS

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In the summer of 1963, W. H. Brener, Supervisor of Wisconsin State Nurseries, informed the author of a large-scale experiment involving application of Craig mylone (3,5-dimethyl-tetrahydro-1,3,5-thiadiazin-2-thion). This herbicide was used in the spring of 1960 on white spruce beds at a rate of 580 pounds per acre of 50-D (50 percent dust) and 350 pounds per acre of 85-W (85 percent wettable powder). The chemicals were applied about a month ahead of seeding, on alternate beds, leaving untreated beds to serve as con-

trols. In the fall of 1962, the 3-year-old white spruce seedlings on untreated and treated beds showed striking differences in their height growth and height variability. The stock on untreated beds was much shorter, and its height was more uniform, with a coefficient of variability of 9.5 percent. The stock on treated beds had some seedlings of enormous heights, exceeding 20 inches, and also a very high coefficient of variability, 22.3 percent.

Four soil samples, each consisting of seven 6-inch cores, were collected using a calibrated sampling tube from the untreated and herbicide-treated beds. Samples of stock were taken with the help of a sampling board (1). The results of these soil analyses (table 1)

¹ The author is indebted to R. R. Maeglin, U.S. Forest Products Laboratory, Madison, Wis., for determining the specific gravity of seedling stems.

TABLE 1.--State of soil fertility factors in untreated nursery beds and beds treated with Craig mylone herbicide (Griffith State Forest Nursery, Wisconsin)

Sample No.	Reaction pH	Organic matter	Total N	Available P ₂ O ₅	Available K ₂ O	Exchange Ca	Exchange Mg
Untreated nursery beds							
		Percent	Percent	Lbs./a.	Lbs./a.	M.e./100 g.	M.e./100 g.
.....	5.3	2.0	0.082	205	261	0.97	0.38
.....	5.3	1.8	.077	217	261	.97	.35
.....	5.2	2.2	.093	212	232	.82	.29
.....	5.2	2.4	.100	205	252	.85	.31
Average.....	5.25	2.1	.088	209.8	251.5	.90	.33
Herbicide-treated beds							
.....	5.1	1.8	0.073	217	227	0.60	0.20
.....	5.1	1.9	.082	217	242	.60	.22
.....	4.9	2.3	.094	179	213	.50	.19
.....	4.9	2.1	.091	189	208	.50	.16
Average.....	5.00	2.0	.085	200.5	222.5	.55	.19

TABLE 2.--Morphological and anatomical characteristics of 3-year-old white spruce seedlings raised on untreated soil and soil treated with Craig mylone. Results per average seedling

Nature of nursery stock	Height	Diameter	Height-diameter ratio	Ovendry weight		Top-root ratio	Titration value of roots	Drought-resistance quotient	Specific gravity	Mycorrhizal roots
				Tops	Roots					
Untreated.....	Cm. 21.3	Mm. 2.8	7.6	Grams 3.01	Grams 0.79	3.8	Me..3NHCL 0.233	7.7	0.473	abundant
Herbicide treated.....	36.0	3.6	10.0	3.33	.51	6.5	.175	5.3	.386	sparse

show very uniform fertility; differences were not statistically significant. A slight decrease in the pH value and available nutrients in soils of herbicide-treated beds should be attributed to a more intense feeding of the larger stock.

Morphological and anatomical analyses (table 2) have provided results which strongly suggest that the eradicator harmed the vigor or quality of seedlings. The most significant adverse features of stock produced on herbicide-treated beds are as follows:

1. Excessive height-diameter ratio predisposing seedlings to lodging and damages by snow.

2. A very abnormal top-root ratio of 6.5 and very low titration value of roots, suggesting inadequate drought resistance of seedlings.

3. A drastic decrease in the specific gravity of herbicide-treated stock, further aggravating the vulnerability of seedlings that are already affected because of their unbalanced height-diameter ratio.

4. The scarcity of mycorrhizal roots, which may handicap the uptake of nutrients by seedlings during their initial growth under field conditions. The morphology of seedlings produced on biocide-treated and untreated beds is illustrated in figure 1.

The results of foliar analyses (table 3) indicate that herbicide treatment lowered the concentration of alcohol-benzene solubles and promoted an abnormally high uptake of nutrients or a "luxury feeding" of stock. Both of these alterations may facilitate the attack of parasitic organisms.

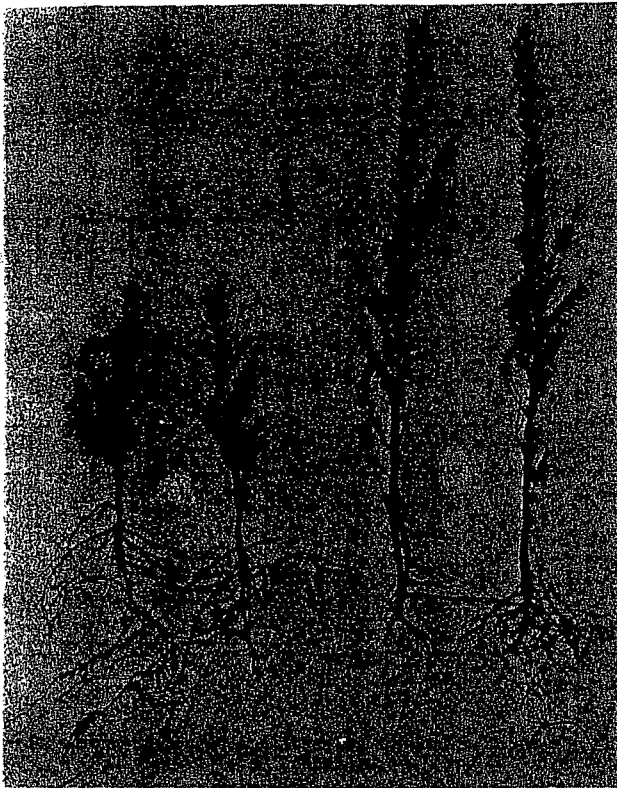


Figure 1.-Morphology of seedlings produced on herbicide-treated beds (left) and untreated beds (right).

Little information has been obtained on the relative survival and growth potential of the two kinds of nursery stock. It was noted that the seedlings lifted from herbicide-treated beds lost most of their needles within a few days upon air-drying, whereas seedlings from untreated beds retained their foliage for 3 to 4 weeks.

The pitfalls occasionally encountered in artificial propagation of plants were known as early as 600 B.C. In one of his fables, Aesop tells about a man asking a gardener a pertinent question: "Why are wild plants strong and thriving, while the cultivated ones are spindly and wilted?" In Aesop's day the reason was most likely a depletion of cultivated soils of fertility; in our time the same results are often due to excessive use of fertilizer salts, particularly nitrogen, and eradicants which upset the normal balance of plants by their unreasonable growth-promoting influence.

Literature

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TABLE 3.--Foliar analyses of 3-year-old white spruce seedlings raised on untreated soil and soil treated with Craig mylone. Results per average seedling

Nature of nursery stock	Munsell color notation	Organo-solubles	Ash	N	P	K	Ca	Mg
Untreated.....	7.5GY 4/4-5/4	Percent 35.5	Percent 5.65	Percent 0.99	Percent 0.107	Percent 0.356	Percent 0.483	Percent 0.067
Herbicide treated..	7.5GY 3/4-4/4; 5.PYR. 4/6	30.6	4.55	1.28	.127	.391	.720	.145

Rotteveel, A. J. W. Naber, H. 1987.

The use of soil fumigation against yellow nutsedge.

Mededelingen van de Faculteit Landbouwwetenschappen Rijksuniversiteit Gent.
1987. 52: 3b, 1207-1212.

Abstract

This is the text of a paper given at the 39th International Symposium on Crop Protection. The results are given of 5 experiments, 2 in autumn as part of a maize cropping system and 3 on fallow land in July. Metham sodium was more effective than dichlorpropene but as effective as dichlorpropene + methylisothiocyanate. Methyl bromide proved most effective but no treatment completely eradicated *Cyperus esculentus*. Tubers appeared to survive below the tillage depth and some even survived in the top layer of soil.

Determinants of Reforestation Behavior Among Southern Landowners

JACK P. ROYER

ABSTRACT. Accurate models of reforestation behavior are important to projecting the nation's softwood timber supplies and deciding on appropriate public responses, if any, to encourage tree planting. Logistical regression models of the reforestation behavior of southern landowners show the probability of actively regenerating pine on cutover timberlands to be a function of market and policy influences, provided the landowners are in a financial position to consider investments, are not constrained by competing land management objectives, and are informed about reforestation opportunities. Landowners are most sensitive to reforestation costs, cost-sharing, income limitations, and technical assistance. *FOR. SCI.* 33(3):654-667.

ADDITIONAL KEY WORDS. Timber supply, economics, investment, logistical regression.

OVER THE PAST DECADE, the planting of pine has more than doubled on nonindustrial private forest ownerships in the South, but reasons for that trend are not clear. Some of the increase is likely due to increased harvests across the South. Nonetheless, markets for southern pine have generally improved, and public forestry incentives have been initiated to encourage reforestation. For example, the USDA Forest Service (1982) reports that nearly 70% of the forestry investment opportunities estimated to yield 4% or more after inflation are found on nonindustrial private forest ownerships in the South. These opportunities represent market signals that should encourage reforestation. At the same time, however, nearly three-quarters of the cost-share payments under the federal Forestry Incentives Program have gone to the South for pine reforestation (Risbrudt and Ellefson 1983). These payments raise the prospect of a policy influence. The relative importance of public versus market influences has rekindled debate over the appropriate role, if any, for government in nonindustrial private forestry (Bethae and Wishart 1984, Jackson 1984, Popovich 1984, USDA Forest Service 1984). Moreover, it has given rise to a need for systematic analyses of the determinants of reforestation behavior—analyses that address both market and policy influences.

The econometric analysis in this paper examines the reforestation behavior of southern landowners, focusing specifically on the effects of markets, public policies, and landowner characteristics. Following a brief discussion of the structural properties of forestry investment models, a model of reforestation behavior is specified, drawing primarily on the theoretical discussions of McMahon (1964). McMahon casts forestry investment behavior as a function of both owner and investment characteristics, maintaining that owner characteristics determine whether a landowner becomes an investor (vs. remaining a consumer), while characteristics of the invest-

ment opportunity determine whether tree planting is chosen over investments. The model derived is estimated using logistical regression and data from a southwide survey of 251 nonindustrial private forest landowners who conducted final harvests on pinelands between 1971 and 1981 in one of 12 southern states (Pecso et al. 1982). The sample represented the population of southern landowners who faced a reforestation decision after harvest and may have been influenced by market signals or public programs. The exogenous parameters in the model include stumpage prices, reforestation costs, government cost-sharing, landowner income, land management objectives, and technical assistance. The dependent variable of interest is the probability that a landowner reforests after harvesting.

MODEL DEVELOPMENT

Numerous landowner surveys since the 1940s have examined forestry-related behavior,¹ but the analysis of data from those surveys has typically been limited to correlating forestry practices with owner and ownership characteristics. Market and policy influences have been investigated in more recent studies (cf. Heaps and Neher 1979, Binkley 1981, Chang 1983, McConnell et al. 1983, Hardie et al. 1985, and Newman et al. 1985). The emphasis of these latter works, however, has been on short- rather than long-term timber supply (i.e., the choice to harvest rather than the choice to reforest).

Exceptions to these patterns are found in the recent works of several forest econometricians, notably Cohen (1983), Boyd (1984), de Steiguer (1984), and Brooks (1985). These researchers have explored reforestation investments in the South and their works serve here as a point of departure for the discussion of a model of reforestation (vs. harvesting) behavior. The models adopted by these four researchers are drawn from microeconomics, investment theory, and utility theory, and in each case focus on reforestation as it is affected by pine stumpage prices and government cost-sharing. The models of Cohen and Brooks further explore the effects of reforestation costs; those of de Steiguer and Cohen address the constraint of wealth; Boyd extends his model to professional forestry assistance, farm occupation, education, and absentee ownership.

The upshot of these models has been some degree of convergence on a broadened array of structural parameters important to forestry investment behavior. Nonetheless, a cursory examination of the empirical results of these studies reveals problems of consistency among the findings. The estimated coefficients for stumpage prices, reforestation costs, landowner income, and cost-sharing vary either in statistical significance or sign across the four models. For example, Cohen and Boyd report positive and significant coefficients for stumpage prices, while de Steiguer and Brooks report no demonstrable effects for their price variables. Reforestation costs are reported to have no significant effect by Cohen; Brooks, in contrast, reports a strong negative effect, but only in the south central states, not in the southeastern states. Cohen and de Steiguer demonstrate an income constraint, while Boyd reports an ambiguous effect for that variable. Finally,

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¹ Some key studies from the literature include: Folweiler and Vaux 1944, Barraclough and Rettie 1950, James 1950, Mignery 1956, Yoho and James 1958, Webster and Stoltenberg 1959, Perry and Guttenberg 1959, Webster and Stoltenberg 1959, James and Schallau 1961, Keniston 1962, South et al. 1965, Somberg 1971, Holemo and Brown 1975, Kingsley and Finley 1975 (among others at the Northeastern Forest Experiment Station), and Marlin 1978.

Boyd and Brooks report cost-sharing to have a positive influence on reforestation; Cohen reports a negative effect.²

These findings raise questions about the determinants of reforestation behavior, and they present mixed signals about appropriate policy directions. Boyd, for example, contrasts his coefficient for cost-sharing with that for technical assistance, concluding that a better means of increasing timber outputs would be to supply information rather than subsidies. Cohen also argues against public cost-shares, noting evidence of the substitution of public capital for private capital. Brooks, in contrast, concludes that increased cost-sharing could have a highly desirable effect on future timber supplies.

As a result of these differences, the strategy adopted for this analysis was not to subscribe initially to the model of any one previous researcher, but rather to examine the structural parameters of these models and work toward a composite specification of a reforestation model based on good theoretical constructs and the possibility of resolving some of the discrepancies in the four previous studies. To this end the theoretical discussions of McMahon (1964) were particularly useful.

McMahon assumes that forest landowners face two basic choices—first, to consume or invest, and then, if the choice is to invest, to invest in reforestation versus some nonforestry investment. He further maintains that the marginal costs of the first choice should be higher than those associated with the second and should be primarily a function of the landowner's income or asset levels. That is, when current income is limited or asset position is low, a landowner will typically use his income or capital to meet current wants, i.e. to consume, rather than to invest. When income and capital are not as limiting, the choice to reforest becomes a question of the competitiveness of returns from tree growing compared to alternative forms of investment, with the marginal cost of investing approaching market rates.

Based on this conceptualization, McMahon posits effects from two categories of exogenous variables: the characteristics of the landowner—those that constrain his ability to become an investor—and characteristics of the investment opportunity—those that determine its “earning capacity” as compared to other investments. McMahon identifies the landowner characteristics important to forestry investments as the landowner's economic situation (his income and asset position), his land management goals, and his knowledge of forestry investment opportunities. Investment opportunity, according to McMahon, is shaped by the expected rate of return, the ease with which that rate is determined, the risk of physical loss, the liquidity of the investment, and the level of government subsidy.

² Some of the differences in the four studies may have stemmed from the type or quality of data used; still others may have resulted from the slightly varied definitions of the dependent variable. Three of the researchers (Cohen 1983, de Steiguer 1984, and Brooks 1985) used time-series data aggregated at the state level to estimate their models, choosing either total acres planted or autonomous (unsubsidized) acres planted as dependent variables. These estimations may have produced varying results because of the assumptions necessary about lagged relationships or difficulties encountered in measuring variables when using aggregated data. Planting records in the South have typically been fraught with errors, including the reporting of more cost-share acres in some years than total acres planted. The researchers who used these aggregated data recognized this problem, but had no way of correcting for it. Boyd avoided these problems by using microlevel survey data; the results of his study may have been affected by its limited geographic scope and the direct extension of the structural parameters of the model of harvesting choice to that of reforestation choice.

Based on these arguments, a model of reforestation behavior can be specified as:

$$Y = f(M, G, I, O, K) \quad (1)$$

where

Y is reforestation investment

M is the earning capacity of reforestation as dictated by market conditions

G is government incentive through cost-sharing

I is the landowner's income or asset position

O is the landowner's land management objectives, and

K is the landowner's knowledge of reforestation investment opportunities

In this model a landowner who has harvested timber is assumed to compare returns from reforestation investment with returns from other investments considering government cost-sharing, and to respond accordingly, provided his opportunity to respond is not constrained by limited income, nonforestry objectives, or ignorance of reforestation opportunities.

Thus, like the four models discussed above, the model in Equation (1) casts reforestation behavior primarily as a function of pecuniary interest, with stumpage prices, reforestation costs, and cost-shaping that interest. Moreover, like the models of de Steiguer and Cohen, the model posits an income constraint, and like Boyd's model, it includes a role for technical assistance from professional foresters—the primary means by which a landowner learns of reforestation opportunities. Finally, the model incorporates nontimber objectives.

The task at hand, then, is to estimate the parameters of the model, looking specifically at relative importance of the structural parameters in Equation (1), possible reasons for the inconsistencies among other reforestation models, and the policy implications of the findings.

ESTIMATING THE MODEL

Data to estimate the model were derived from personal interviews with 251 nonindustrial private landowners who had conducted final harvests on 10 or more acres of pineland between 1971 and 1981 in one of the 12 southern states comprising the southern pine region: Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, Virginia, and the eastern parts of Oklahoma and Texas. The sample frame used to identify these owners was area-frame sample maintained by the USDA Statistical Reporting Service. Details of this frame and the sampling and survey procedures for the landowner interviews are described in Fecso et al. (1982). The 251 landowners used in the analysis were the landowners who had either clearcut or used a seed tree cut as a method of harvest; landowners who had conducted commercial thinnings or selection cuts were excluded. The sample thus represented the population of individuals who faced a reforestation decision after harvest and may have been influenced by markets, public programs, or personal characteristics.³ Because the landowners in the sample were distributed widely across the South, the

³ Several points regarding the sample and data are noteworthy here. The decision of interest in drawing the above sample was regenerating cutover pineland to pine. A fuller array of landowner investment decisions, such as whether to harvest, how to harvest, or whether to plant retired agricultural land, also affect timber supply and deserve attention in models. The central importance of reforestation after harvest to southern timber supply led to concentration only on the post-harvest decision for this study.

int low data could be supplemented with cross-sectional measures of stumpage prices and reforestation costs based on the location of the harvested holdings.

The dependent variable defined for the analysis was derived from the survey data and was dichotomous, indicating whether the landowner had actively reforested by replanting or using a seed tree cut. Because this variable was dichotomous, the logit model or logit transformation was used to estimate the model's parameters (cf. Amemiya 1981, Pindyck and Rubinfeld 1981).

Eleven independent variables were identified to represent the five categories of exogenous influences specified in Equation (1). A summary of those variables and their expected signs with respect to reforestation behavior are presented in Table 1.

TABLE 1. Summary of exogenous variables for the logistical regression model of reforestation behavior.

Variable	Measurement	Mean	Min-Max	Std. dev.	Expected sign
Sawtimber prices	6-year average, nominal dollars per mbf, across 35 Timber Mart South regions	\$125.	\$55-\$161	26.89	+
Pulpwood prices	6-year average, nominal dollars per mbf, across 35 Timber Mart South regions	\$11.81	\$0-\$22.53	4.92	+
Reforestation costs	1983 average of FIP cases, \$/ac for low, moderate, and high site preparation plus machine planting across 35 Timber Mart South regions	\$112.	\$74-\$143	20.51	-
Knowledge of cost-sharing	Dummy, awareness of cost-sharing prior to reforestation decision	0.45	0,1	0.50	+
Income	1980 annual household income, thousands of dollars ^a	\$25K	\$3K-\$50K	17.62	+
Forestland holdings	Acres ^b	232.	30-500	175.78	+
Estate plans	Dummy, plans to pass harvested parcel to heirs	0.78	0,1	0.41	+
Farming	Dummy, farming as primary source of income	0.21	0,1	0.41	-
Technical assistance	Dummy, professional forester prepared forest management plan, or retained the services of a professional forester at time of harvest	0.27	0,1	0.44	+

^a From midpoints of categories; all owners above \$45K were assigned income of \$50K.

^b From midpoints of categories; all owners above 500 ac were assigned size of 500 ac.

Market signals were represented by two stumpage-price variable—one for sawtimber and one for pulpwood—and reforestation costs. The two price variables were entered as the average of the annual pine stumpage prices between 1976 and 1981 as reported for the 35 regions of *Timber Mart South*. These prices were not assumed to be the specific prices faced by individual owners; rather, they were assumed to be a measure of the relative price settings across which the 251 holdings in the study were distributed. Price expectations were assumed to form from these relative prices, thus the regression analysis provided a test of the hypothesis that the likelihood of reforestation was higher in regions exhibiting higher stumpage prices.⁴

Reforestation costs were also computed as a cross-sectional variable, using case data from approximately 3000 participants in the federal Forestry Incentives Program during 1983.⁵ The average of the costs for three site preparation intensities—light, moderate, and heavy—plus the costs of machine planting were used to derive a composite cost estimate for each group of counties comprising the 35 *Timber Mart South* regions. The costs applicable to any given landowner were not known, so the cost variable, like the price variable, was assumed to be an indicator of the relative cost settings from which landowner expectations about reforestation expenses were formed. Higher average costs in a region were expected to lower the likelihood that a landowner reforested.

The earning potential of reforestation was expected to be further influenced by government cost-sharing. The cost-share variable was measured as a dichotomous variable, indicating whether a landowner was aware of the cost-sharing assistance available through the federal Forestry Incentive Program or one of the three cost-share programs operative among the southern states during the 1971-1981 study period. Awareness of the availability of cost-sharing was expected to have a positive effect on the probability of reforestation.⁶

Income and size of forest landholdings were entered as measures of the landowner's asset position. Both were collected as categorical variables during the interviews and then transformed to continuous variables using the midpoints of the categories. The model suggests a higher income should reflect an increased likelihood to reforestation because of the reduced constraint on becoming an investor. Size of holdings was also expected to exhibit a positive sign—the result of higher capital availability and perhaps increased economies of scale.

Constraints on the probability of reforestation were expected to arise from the dependence of a landowner on farm income and from the absence of plans to pass land on to heirs.⁷ Other factors being equal, farmers were

⁴ The implicit assumption here is that returns from reforestation occur only upon harvesting when timber becomes mature. Some return to tree planting may occur, however, if the planted land is sold and the value of the young timber is reflected in the selling price. No direct measures of timberland property value were available for inclusion in the model, although a partial test of the landowners' perception of timberland values was provided by the variable reflecting the land disposition plans of the landowners (see footnote 8).

⁵ The author wishes to acknowledge the assistance of Dr. J. Michael Vasievich of the Southeastern Forest Experiment Station for his cooperation in providing these data.

⁶ Knowledge of cost-sharing was used rather than receipt of cost-sharing, because in causal modelling the cause must precede the effect.

⁷ The variety of alternative land management objectives a landowner may follow makes model specification particularly difficult here. One often encounters references to "nontimber" objectives in the forestry literature where the term usually applies to esthetic, wildlife, or recre-

expected to be less inclined to reforest because of their propensity to use available capital for their farm operations rather than their woodlands. This is not to imply that farmers are less rational in response to economic opportunities than nonfarmers. The responsiveness of farmers to economic opportunities is tested in the price and cost variables. Moreover, any income limitations unique to farmers are tested by the income variable. The farm variable was entered simply to test whether farm operations compete for capital with forest operations and thus reduce the likelihood of reforestation. One could alternatively argue that farmers might be more inclined to understand the need for reforestation and perhaps be more familiar with assistance programs. The negative relationship posited was based on the notion that, other factors being equal, farmers are inclined to support their farm operation before investing in their woodlands. The farm variable was a dummy variable reflecting whether more than half of the landowner's income was derived from farming.

Landowners with plans to pass their land on to their heirs were expected to be more likely to reforest because of the retained family interest in the land.⁸ The variable for these plans was determined from the interviews and was entered as a dummy.

Finally, the landowners' contact with professional foresters was entered as a measure of the knowledge level of landowners.⁹ The measure of technical assistance was entered as a dichotomous variable, which was assigned a value of 1 if the landowner retained the services of a professional forester at the time of harvest or if the landowner had a professional forester prepare a forest management plan for the harvested parcel prior to the sale. Contact with a professional forester, public or private, was expected to enhance the likelihood of reforestation.

RESULTS

The estimated model (Table 2) shows McMahon's conceptualization of for-

estational values that are compromised when harvesting occurs. The decision being modeled in this study is not the harvest decision, however; rather it is the reforestation decision after clearcutting. The effect of esthetic and recreational values may come into play when the decision to harvest or the method of harvest are being considered, but it is not likely that the tradeoff of those values is important once that land has been clearcut and the decision becomes whether to replant. Hence, competing objectives other than the conventional timber versus nontimber tradeoff associated with the harvest decision were deemed appropriate for this study. The two variables selected for this study are by no means the only ones that can be identified in this category, however, and therein lies the specification difficulty.

⁸ This variable not only tests the estate objective but also tests the landowners' perceptions of returns from timber as compared to returns from timberland. No significant difference between the two groups would suggest that landowners perceive young timber to increase the value of land. That is, they need not wait until a distant harvest to realize a return on reforestation investment.

⁹ Technical assistance was considered to be the best proxy for landowner knowledge despite some obvious liabilities. Some landowners may be highly knowledgeable of pine silviculture and not use professional foresters, in which case misclassification occurs when using contact with a forester. A quiz to determine the forestry expertise of landowners might provide a better measure. But when landowners broker their reforestation decisions to foresters, they may not pass the quiz, yet a great deal of technical expertise is brought to bear on the reforestation decision because of the forester's involvement. The quiz method would thus misclassify this group and the data suggest that many landowners do indeed broker their land management decisions to foresters. As a result the contact with professional foresters was used as the proxy for knowledge.

TABLE 2. Estimated logistical regression equations for the likelihood of reforestation after harvesting in the South, 1971-1981.

Variable	Full model		Reduced model	
	Beta (t-ratio)	Beta/ (t-ratio)	Derivative prob @ mean ^a	Elasticity @ mean ^b
Intercept	-1.1582 (0.73)	-1.9186 (1.71)		
Sawmiller prices	-0.0069 (0.74)			
Pulpwood prices	+0.1319 (1.93)**	+0.1059 (1.70)**	0.016	1.02
Reforestation costs	-0.0290 (1.94)**	-0.0299 (2.01)***	-0.005	2.74
Knowledge of cost-sharing	+3.4819 (6.48)***	+3.3869 (6.72)***	0.547	
Household income	+0.0363 (2.39)***	+0.0348 (2.72)***	0.005	0.71
Size of holdings	-0.0007 (0.49)			
Estate plans	-0.3367 (0.60)			
Farmers	-0.6906 (1.37)*	-0.6755 (1.35)*	-0.899	c
Technical assistance	+1.1689 (2.48)***	+1.0842 (2.44)***	0.188	c
P(Y = 1) @ means	0.180	0.184		
Concordant Pairs ^d	0.907	0.906		
-2 Log L (null)	271.34	271.34		
-2 Log L (model)	151.62	152.89		
Chi-square test of reduced model vs. full model: $\chi^2 = -2(151.62 - 152.89) = 1.46$				

^a $p(1 - p)B$

^b $X(1 - p)B$

^c Not applicable for a dummy variable.

^d The fraction of all observed pairs with discordant values (1,0) for which the predicted probability is higher for the observation with the value of 1 (see Harrell 1983).

*** denotes significance at the 0.05 level

** denotes significance at the 0.10 level

* denotes significance at the 0.20 level

estry investment behavior to be valid—the likelihood of reforestation is a function of both characteristics of the investment opportunity and owner characteristics. The model further discloses that the investment opportunity is shaped by market conditions as well as the availability of public cost-sharing, with landowners being moderately responsive to pulpwood prices and highly responsive to cost-sharing assistance. For some landowners, however, a budget constraint (reflected in the reduced likelihood of reforestation among landowners with modest income) precludes investment. Moreover, the lack of technical expertise further constrains the landowners' responsiveness to favorable investment opportunities.

These effects are seen in the two maximum likelihood logistical regression equations for reforestation behavior in Table 2. Each equation shows the estimated coefficients and asymptotic t-ratios for the parameters of a full and reduced model. In the full model, all of the posited exogenous variables are entered. Six of the variables exhibit the expected signs; the exceptions

an timber prices, size of holding, and estate plans,¹⁰ but none of these variables is statistically different from zero. Of the six remaining variables, four meet the 5% test: costs, cost-sharing, income, and technical assistance. Pulpwood prices nearly meet the 5% test; the farm variable is significant only at the 20% level.

In the reduced model, the variables not meeting the 20% test are eliminated, with little effect on the significance levels of the other regressors. Reforestation costs, government cost-sharing, income, and technical assistance remain highly significant determinants of reforestation, with pulpwood prices also contributing, although at a slightly lower confidence level.

The partial derivatives and elasticities of the probabilities of reforestation from the reduced model are also presented in Table 2 and show the magnitude of the sensitivities of the landowners to each parameter. For example, a 1% increase in reforestation costs (at the mean) decreases the likelihood of reforestation by 2.74%. By comparison, a 1% increase in pulpwood prices results in approximately a 1% increase in the probability of reforestation. Landowners who are aware of governmental cost-share programs are over 50% more likely to reforest than those who are not. Those who are advised by professional foresters at harvest or through a management plan are almost 20% more likely to reforest.

The income elasticity of reforestation behavior discloses that a 1% increase in income (at the mean) results in approximately a 0.75% increase in the probability of reforestation. Further evidence of an income effect can be seen in the separate estimations of the model for landowners with below-versus above-average incomes (Table 3). Among the lower income landowners, costs, cost-sharing, and technical assistance are the key determinants of reforestation choice; stumpage prices and farm occupation do not appear as important parameters. Among higher income individuals, cost-sharing and technical assistance remain important determinants while stumpage prices rather than reforestation costs become the investment parameter eliciting the most response.

DISCUSSION AND POLICY IMPLICATIONS

The above findings have implications for both the modelling of landowner behavior and the policy debate that surrounds southern timber supply. Let me first elaborate briefly on the model and its relationship to other landowner models.

The decision modeled in the above analysis was the decision to reforest after harvesting in the southern pine region. This is just one of several landowner decisions that is important to southern timber supply; others would include the choice to harvest, the choice of harvesting method once a harvest had been elected, and the decision to plant an old field. The impetus for a reforestation model stems from the recent shifts from pine to hardwood that have been attributed to the post-harvest behavior of landowners (Boyce and Knight 1979, Sheffield et al. 1985). The intent of this study was to con-

¹⁰ The negative sign for sawtimber prices is somewhat deceiving. One possible explanation is that where sawtimber prices are high, timber markets are active and landowners are encouraged to harvest. But among these harvesters are the most marginal investors. As a result, good sawtimber prices elicit a harvesting choice but not a reforestation choice. If this is the case, however, pulpwood prices might be expected to also exhibit a negative sign, unless the shorter time frame associated with pulpwood rotations is more consistent with the planning horizons of landowners and is thus a stimulus. More on this possibility is discussed below.

TABLE 3. Estimated logistical regression equations for reforestation behavior among landowners with below and above average incomes.

Explanatory variable	Equation for landowners with incomes under 25K			Equation for landowners with incomes over 25K		
	Beta/ (t-ratio)	Derv at mean ^a	Elas at mean ^b	Beta/ (t-ratio)	Derv at mean ^a	Elas at mean ^b
Intercept	+0.5690 (0.36)			-5.9885 (2.14)		
Pulpwood prices	+0.0858 (0.98)	0.011	0.84	+0.1872 (1.70)**	0.032	1.78
Reforestation costs	-0.0401 (2.01)***	-0.005	-3.78	-0.0085 (0.35)	-0.001	-0.75
Knowledge of cost-sharing	+2.5636 (4.37)***	0.391		+5.6883 (4.38)***	0.803	
Farming as occupation	-0.0072 (0.01)	-0.001		-1.3847 (1.60)*	-0.208	
Technical assistance	+0.6574 (1.16)	0.246		+2.4465 (2.64)***	0.466	
P(Y = 1)	0.22			0.15		
Concordant pairs ^d	0.85			0.96		

^a $p(1 - p)B$

^b $X(1 - p)B$

^c Not applicable for a dummy variable.

*** denotes significance at the 0.05 level

** denotes significance at the 0.10 level

* denotes significance at the 0.20 level

centrate on that behavior. Additional modeling efforts should address other forestry decisions to provide a more comprehensive look at the landowner behavior. Moreover, the landowner behavior should be examined in other parts of the country. The central aim of this analysis, however, was to ascertain the determinants of reforestation behavior in the South—a region in which nonindustrial private landowners hold the majority of the pineland and the majority of tree planting occurs on cutover timberland.

A second point worth noting centers on the use of microlevel data, and their geographic scope. The survey data from the southwide study differ markedly from the aggregated data used by Cohen (1983), de Steiguer (1984), and Brooks (1985) (see footnote 2), even though the goal of these researchers—isolating determinants of reforestation behavior in the South—was similar to this study. Because different data were used, the estimated coefficients from this study are not directly comparable to the above three studies. Nonetheless, the general constructs of the models—e.g., prices, costs, income—gave a common frame of reference. The advantage of the microlevel data lies in the opportunity to specify a fuller model of reforestation behavior, avoiding specification errors due to omission. Moreover, attention can focus more directly on causal linkages. Boyd (1984) used microlevel data to gain these advantages; the primary difference between his data and the data from this study is geographic scope. The southwide data in this study allowed better definition of the cross-sectional market variables and perhaps avoided other local biases.

A third point concerns the measurement of variables—a perennial problem for regression modellers. Efforts were made to identify variables

It accurately represented the categories of influence posited by McMahon (1964). Each variable at best, however, only represents a structural parameter of interest. Questions may thus arise concerning validity of the empirical measures. Several questions are posed here as food for thought, for other researchers who may address landowner behavior in the future: Are current stumpage prices valid measures of market opportunities or are measures such as land rent, perceptions of future prices, or relative changes in forestry versus other commodity prices better indicators? Is income a sufficient indicator of wealth, or should other factors be incorporated? What better measures of landowner objectives can be derived? Finally, how can the marginal effects of knowledge and technical assistance be isolated? Specification and measurement difficulties complicate the modelling of reforestation behavior as each of the four econometricians noted previously. The analysis in this study was undertaken with thorough regard for those notations. Still, opportunity exists to improve further on our modelling methods.

Finally, on the issue of an appropriate theoretical model to explain the reforestation behavior of southern landowners, the study reveals that investment theory as outlined by McMahon (1964) seems accurate. In this respect, the model is similar to the models sketched by de Steiguer (1985), but is unlike the utility-based characterization used by Boyd (1984). Unlike the utility-based harvest decision, in which landowners contrast the relative values of timber and nontimber output, the reforestation decision is governed less by the prevailing market and is shaped by costs and an income constraint. These differences in determinants are important and should be the object of additional theoretical and empirical effort.

Setting these challenges aside, one can further examine the findings of the above analysis with an eye toward possible explanations for recent trends in tree planting in the South and the likely effects of alternative courses of action by public agencies. Recent forest surveys across the South have shown significant declines in the annual growth of pine timber on nonindustrial private ownerships (Boyce and Knight 1979, Sheffield et al. 1985), which in turn have fostered projections of declining pine volumes beginning around the year 2000 and possibly dropping to pre-1970 levels by 2030 (USDA Forest Service 1983). Equilibrium models considered these supply changes in light of increasing demand forecast real price rises for pine stumpage in the range of 2 to 3% (USDA Forest Service 1983). These increases should represent inducements to reforest, provided landowners are sensitive to price signals. The regression discloses that southern landowners are compelled only modestly to reforest by a price stimulus; they tend to be more significantly affected by costs, cost-sharing, income limitations, and technical assistance. This is not to say that landowners are insensitive to prices; indeed the findings suggest landowners are perhaps far more discriminating with respect to prices than past studies would lead us to believe.¹¹ The landowners sensitivity to pulpwood prices but not sawtimber

¹¹ In two of the four recent studies, the price variable was not significantly different from zero, raising questions about the importance of a price influence. This may have resulted from the use of historical data from national forest timber sales or the Louisiana price series to derive the stumpage price variable—the only option available when using time series data prior to 1976, the first year *Timber Mart South* began publication. Also, in each past study, only a sawtimber variable was examined. The two stumpage price variables in this study were cross-sectional and based on a broad geographical area.

prices indicates a responsiveness only to price signals that corresponds to shorter investment horizons—those for pulpwood rotations rather than sawtimber rotations. This is consistent with the notion that landowners apply high discount rates to their investment decisions, the likely effect being that timber outputs from nonindustrial private forest holdings will be below those expected under the assumptions of lower discount rates and sensitivity to a fuller range of prices.

A market parameter with seemingly greater influence of reforestation behavior is the cost of reforestation. Unlike price expectations, the costs of preparing and planting a harvested site are more immediate and therefore more easily compared to alternative rates of return during the reforestation decision. This is a likely reason for the nearly three-fold difference between the elasticities for prices and costs. That difference is important because it suggests that trends in reforestation costs will be more critical than trends in prices; equal relative increases in costs and pulpwood prices would result in a reduced likelihood of reforestation—the negative effects of costs more than offsetting the positive effects of prices. This high sensitivity to costs, especially among landowners with modest incomes, suggests that low-cost reforestation techniques may hold the key to increasing reforestation in the South.

The importance of costs is further reflected in the sensitivity of landowners to cost-sharing. Regardless of their financial position, landowners are highly responsive to cost-sharing. For landowners with below-average incomes, this would seem to indicate a way to overcome capital constraints; for landowners with above-average income this would seem to be a way of making the reforestation investment more competitive with other investments. Some substitution of public capital for private capital likely occurs in this latter group, nonetheless the strength of the cost-share coefficient suggests that much of the effect is additive. That is, cost-sharing serves as an inducement to reforest, even among landowners not constrained by capital. The strength of the cost-sharing coefficient suggests much of the increase in reforestation in the South has been stimulated by federal and state cost-sharing. Continuation of such programs would seem prudent in light of the mixed responses to price signals.

The overall effects of prices, costs, and cost-sharing illustrate that the market and policy settings in which landowners make reforestation decisions are important. This holds, however, only for landowners who are in a financial position to take advantage of favorable conditions and who are aware of the opportunities before them. The marginal costs of investing are simply too high considering the asset position (income) of some landowners; their behavior is restricted largely to consumptive activities. The model thus supports the notion of an income constraint as posited by de Steiguer (1984) and Cohen (1983).

Still other landowners are constrained by the lack of technical information, as Boyd (1984) has suggested. The estimated model clearly indicates that contact with professional advisors enhances the likelihood of reforestation. This finding, coupled with the high sensitivity to cost, suggests that professional assistance from public or private foresters aimed at low-cost reforestation alternatives would seem to pay high dividends. But emphasizing technical assistance to the exclusion of financial assistance, as recommended by Boyd (1984), may be ill-advised. Applying Boyd's test of coefficients to the technical assistance and cost-sharing variables in this study yields a contrasting conclusion: South-wide, landowners were more respon-

sive to financial than technical incentives.¹² Lack of technical knowledge is a constraint on investment, but pecuniary constraints are also highly important. Both financial and technical assistance seem imperative if the nation's goal is to increase reforestation rates on southern pinelands.

This raises an important question for observers of forest policy: What role, if any, should government play in nonindustrial private forestry? The isolation of reforestation determinants in the above model is a positive (as opposed to normative) exercise; it tells us *what is*, but not *what ought to be*. As decision units, nonindustrial private owners do not enjoy the longevity of corporations, institutions, or even agencies as investors, and as a result, are characterized by high alternative rates of return, which often lead to the rejection of the reforestation option. Until we see forestry investment decisions shift away from individuals and toward the partnership, corporation, or institution (and there is evidence of growing interest in reforestation among these nontraditional investors (Goetzl and Royer 1982)), programs of financial and technical assistance seem imperative. But while these programs are carried, researchers and analysts have the responsibility to ask what market mechanisms and institutional changes can be identified that would increase landowners responsiveness to reforestation and reduce our dependence on public programs.

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¹² Comparing these coefficients may be an errant strategy. The units of measurement differ, and the precision of those measurements is limited. The cost-shaking variable reflects knowledge of a program; professional assistance reflects actual contact with an individual.

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Soil Fumigation at J. Herbert Stone Nursery¹

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Abstract.—A brief discussion of the history, and current fumigation operations and experiences at the J. Herbert Stone Nursery. Also a post script to this presentation.

INTRODUCTION

The J. Herbert Stone Nursery (JHSN) was established Through a joint effort between the USDA Forest Service and Bureau of Land Management. The site was obtained in two purchases in 1976 and 1982. It is administered by the Rogue River National Forest. The nursery is located in Southwestern Oregon near the towns of Central Point and Medford, Oregon. The total area of the Nursery site is 306 acres with approximately 213 acres of seedling production area. Douglas-fir makes up approximately 608 of the production although a total of 18 - 22 species are produced each year.

The climate is described as "mediterranean" having hot-dry summers, a long growing season and wet-mild winters. The established lifting window for the "dormant plant" lifting season is between December 1st and March 1st.

Most of the nursery's clients are made up of several National Forests and Bureau of Land Management Districts within the southwestern quarter of Oregon and the northern portion of California. Some specialty products such as 1-0 Western larch are being produced for clients as far away as Northern Idaho and Western Montana.

Age classes being grown include both 1-0 and 2-0 ship seedlings with a minor but increasing number of 1-1 transplant seedlings being ordered. These different species and age classes are further divided into a complicated array of "cultural groups" in order to custom grow seedlings which meet the different morphological characteristics requested by the clients while still producing plants that are phenologically sound for lifting, handling and transplanting. The "target seedling" concept has been used for several years to establish the range in options which are available to clients have when ordering seedlings.

PAST EXPERIENCES WITH FUMIGATION

Soil fumigation has been a standard part of the nursery production program since the first seed was sown in the spring of 1978. The original fumigant used was a mixture of 67% methyl bromide and 33% chloropicrin (MB-C). This material was applied and covered with plastic tarp in the standard manner. It was always applied by a fumigation contractor. Fumigation was generally done in the fall before sowing. There have been small areas fumigated in the spring when there were seedlings still occupying areas designated for sowing the following spring. In these cases, the seedlings were removed during the winter lifting season and the fumigation was completed as soon as the soil was in acceptable condition that spring.

Fumigation has always been done for the control of soil born pathogenic fungi which are known to cause pre and post germination dampening-off as well as root rot during later plant development. The pre and post fumigation soil tests have consistently shown that MB-C is a highly effective fumigant for the pathological fungi which were considered threatening at this site.

However, there has been an increasing concern over the continued use of MB-C. This concern has developed from several factors. There has been rumors that MB-C may be more stringently regulated or even banned from use. There have also been rumors about tighter controls on the disposal of the tarp and other materials which have been in contact with the chemical. One nursery had an incident involving this material as well as other factors which led to an administrative decision to ban the use of the product at that site. Recent experiences with poor contractor safety and performance at JHSN has also been a major factor in searching for an alternative product.

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The development of a new formulation of the fumigant dazomet known as Basamid^R spurred the Nursery Management and the Forest Pest Management people in the Forest Service Regional Office in Portland, Oregon to look into the use of this new product as a nursery fumigant. Several tests have been conducted at JHSN over the past several years.

The first test involved several small plots in a single seedling bed. Different levels of dazomet were incorporated into plots. Pre and post fumigation soil analysis was done to evaluate the effectiveness of the material. Seedlings were also grown in these plots and evaluated. The data was very encouraging so the following year, an area of approximately one acre was not fumigated with methyl MB-C. The standard fumigation layout in this field required that fumigation be done perpendicular to the way the seedbeds run. Therefore, the area left untreated ran across an entire field of seedbeds. This area was later treated with dazomet. Pre and post fumigation soil samples were taken for both fumigants for laboratory analysis by FPM personnel. The area was sown to several species of seedlings involving many different seedlots. The soil samples proved that, while the dazomet was not quite as thorough as the MB-C, it still performed within the ranges considered to be effective. Informal evaluation of the seedlings growing in the two treatment areas did not detect any differences.

The following year, about half of the ground to be fumigated was treated with dazomet. Again, no differences in effectiveness nor seedling characteristics were noted.

In the fall of 1988, the entire area to be fumigated was treated with dazomet. All went well for several days after the treatment. Then it was discovered that both 1-0 and 2-0 Western white pine in a field east of the treated area was starting to exhibit signs of chemical injury to the needles. The affected needles turned straw yellow to reddish brown within a period of one to three days from the first indications of trouble. This was quite a surprise to the management of JHSN. Up to this point, there had been no indication of trouble with seedlings in areas adjacent to areas treated with this product. There had been discussion with another nursery about observed trouble when it was applied near Western white pine. However, it was thought that being across a major field road which was a distance of over fifty feet would be sufficient to afford protection from any chemical or gaseous drift. In this case, the JHSN damage extended well over 200 feet into the seedbeds with occasional damage over 300 feet into the beds. The damage seemed to be quite selective. Even though there was a gradient of damage from heavy near the fumigation site to minor at a distance of 250-300 feet away from the treatment boundary, there was also a distinct pattern of individual seedlings. Near the treatment site, certain individuals would have 90-100% needle kill while neighboring seedlings would show only minor tip burn. Further away, there were seedlings with one half the length of nearly all their needles burned while adjacent seedlings showed no symptoms.

This event also surprised the chemical dealer and manufacturer. They had been involved with the JHSN testing and use from the very first tests. The application of the chemical had even been video taped at the JHSN location as a demo on how to apply it on a large scale operation.

Having experienced this event, the management of JHSN is looking at how to prevent a similar occurrence in the future. It is felt that this is an effective alternative to the use of MB-C and its continued use is justified. Proper precautions, however, must be taken when it is used in areas near plants which are apparently susceptible to it or its by-products.

The reasons for this incident and the causal agents have been discussed at length. We are virtually certain that the problem was not caused by drift of the product during application. The application was done under carefully monitored conditions and the damage did not appear for some days after application. It was noted that there had been a weather incident after the application during which there had been particularly still mornings. This is not unusual in the Rogue River Valley in which the nursery is located. This type of condition, known as an air inversion, traps air in the entire valley but is also noticeable within local areas of the valley when ground fog lays just a few feet off the ground and there is no noticeable movement of the local air. It is conjectured that such a condition led to the buildup of escaping by product gasses from the dazomet into some level of concentration at or near the ground surface. This concentration could have then moved slowly down drainage across the area of Western white pine. The affected area was located at a lower elevation than the treated area and the pattern of damage supports this idea.

Future use of this product must be more carefully planned. Among the measures being considered at this time include: Treating smaller areas within a given time frame (approximately 20 acres had been treated in one application day in the case of the damage to the Western white pine). Perhaps treatment with another fumigant should be used when the area is near the susceptible species. Better sealing techniques may be required such as using plastic. The weather patterns may be more carefully monitored to avoid still air and inversion conditions. Other more radical treatments have also been considered. Using a fan system such as used for slash burning or orchard frost protection may provide the air movement needed to prevent damage to susceptible species. A barrier such as a plastic covered fence may detour the air around the area to be protected. There may be other methods of protection as well.

A POST SCRIPT TO THE PAPER

Dazamet was used again in the fall of 1989. Prior to treatment, a few methods of protecting Western white pine seedlings which would again be near the

treated area were evaluated. A barrier of plastic over shade frames was placed down slope between the Western white pine and the treatment area. Smoke from torches was released on the treatment side of the barrier on a "still" morning. The smoke simply built up and crawled over the 4-5 foot high fence. A large gas powered fan used to fire piles of forest logging slash was placed in different positions around the barrier. This offered little or no protection as the smoke went over, around, and past the fan.

Finally, it was decided that the only protection that could be counted on was distance or being totally down wind from susceptible species. A small contract was let to use MB-C adjacent to two areas of Western white pine. One area adjacent to Western white pine transplants was completely treated with MB-C. The other area was treated for a distance of 250 feet from the Western white pine. The results were that the area totally treated with MB-C has no noticeable affects from the fumigation. However, the Western white pine that was within 250 feet of the dazamet was again seriously affected. This time, no affects were observed for several days after treatment. Then, after another heavy-still morning, the needles on the Western white pine started turning. Again, a definite pattern is noticeable across the area of seedlings. A portion of the area which is at the same elevation or higher than the treated area had no damage. The damage also grades out as the distance from the treated field increases. There is again, a noticeable difference between damage to individual seedlings adjacent to each other.

THE FUTURE

The old adage "if he does it to me once, shame on him - if he does it to me a second time, shame on me" is beginning to nag at the management at JHSN. We know that dazamet is a useful tool and a good alternative to using MB-C. We feel that we need to keep both of these chemicals available for selective use as needed. The fact that Western white pine can be damaged when dazamet is used in the vicinity attests very strongly to the need for alternatives. We had sown the two age classes of Western white pine involved in this damage in the center of the nursery not anticipating any problems. Last spring (1989) we located the Western white pine in an area of the nursery which is up drainage and generally upwind from any other field at the nursery. We will continue to locate this species into areas which are not susceptible to the downwind or down drainage conditions which led to the damage of the past two seasons. In addition, we will be looking very hard at using MB-C in any area that is within 500 to 700 feet of Western white pine seedlings. We know now that preventive steps must be extra ordinary. The 250 foot buffer was simply not sufficient.

We have also been working on other treatments to give us additional tools in the fight against pathogenic fungi. We have participated with several other nurseries in a contract with a local University to study fusarium. This work has shed some light on management options which may one day help control this pathogen. Other treatments and management techniques will be evaluated in the future as organic methods become better understood and alternatives to chemical control are developed.

Chloropicrin as a soil fumigant in forest nurseries

by David B. South, William A. Carey and Scott A. Enebak

Chloropicrin has been tested as a soil fumigant in forest nurseries throughout the world. From 1944 to the late 1960's, tests were conducted in Australia, Canada, Netherlands, New Zealand, the United Kingdom and the United States. Since 1985, studies have been conducted in Georgia, Mississippi, South Carolina, Texas, Virginia, Washington and Wisconsin. In Wisconsin, chloropicrin reduced soilborne pathogens as effectively as twice as much methyl bromide. Advantages of chloropicrin as a soil fumigant in southern pine nurseries include: efficacy similar to methyl bromide (in regards to reduction in fungi, nematodes and insects), an increase in *Trichoderma* populations, it is not a Class I ozone depleting substance, and no plastic tarp is required. Adding chloropicrin to other fumigants has increased the spectrum of biological activity. A disadvantage of chloropicrin is that it has less herbicidal activity than methyl bromide.

Key words: fungicide, methyl bromide, disease, nursery management, seedbeds

La chloropicrine a été testée en tant que fumigène des sols dans les pépinières forestières de tous les pays. De 1944 à la fin des années 60, des essais ont été entrepris en Australie, au Canada, aux Pays-Bas, en Nouvelle-Zélande, au Royaume-Uni et aux États-Unis. Depuis 1985, des études ont été réalisées en Géorgie, au Mississippi, en Caroline du Sud, au Texas, en Virginie, dans l'État de Washington et au Wisconsin. Au Wisconsin, la chloropicrine a réduit les pathogènes pédologiques aussi efficacement que deux fois le niveau atteint avec le bromure de méthyle. Les avantages de la chloropicrine en tant que fumigène des sols pour les pépinières de pin du sud comprennent: une efficacité semblable au bromure de méthyle (par rapport à la réduction des champignons, des nématodes et des insectes), une augmentation des populations de *Trichoderma*, il ne s'agit pas d'une substance dégradant l'ozone de classe I, et elle ne nécessite pas de toile de plastique. L'addition de la chloropicrine aux autres fumigènes a augmenté le registre d'activité biologique. Un désavantage de la chloropicrine réside dans une action phytocide moindre que le bromure de méthyle.

Mots clés: fongicide, bromure de méthyle, maladie, gestion de pépinière, planches d'ensemencement

Introduction

Chloropicrin has a specific gravity of 1.66 and a vapor pressure of 18.3 mm Hg (at 20°C). It is a colorless liquid with an intensely irritating odor, commonly known as tear gas and is a restricted use pesticide. The boiling point (112.4°C) is higher than water and the gas is about 5.7 times heavier than air (Sassaman et al. 1986). It is slightly soluble in water (2,000 ppm). On a weight basis, chloropicrin is the second most commonly used fumigant in forest nurseries in the United States. In the southern states, more than 20 tonnes of chloropicrin are used annually to produce one billion pine seedlings. Currently, chloropicrin is added to methyl bromide as a warning agent to enhance safety or it is added to enhance fungicidal efficacy (e.g. 33% chloropicrin and 67% methyl bromide). It is also used in combination with other fumigants such as 1,3-dichloropropene. Even when used as the only active ingredient, chloropicrin can be an effective soil fumigant (Jackson 1934; Stark 1948).

Early Nursery Trials

Chloropicrin has been tested in forest nurseries throughout the world. In 1944, a test was conducted in a nursery in the state of Washington (Breakey et al. 1945). Douglas-fir (*Pseudotsuga menziesii* Mirb.) seedbeds containing seed-corn maggots (*Hylemyia cilicrura*) were fumigated in mid June. Seed were sown a week later on June 25. At time of sowing, "the fumes of chloropicrin were still coming from the soil in appreciable amounts..." Chloropicrin reduced injury from the seed-corn maggot and "the bed which had been treated with chloropicrin

was outstanding in the uniformity and vigor of the young fir seedlings."

In 1947, seedbeds of longleaf pine (*Pinus palustris* Mill.) and slash pine (*Pinus elliotii* Engelm.) were treated in Mississippi (Lindgren and Henry 1949). Seeds were sown on March 18, at least two weeks after treatment. Chloropicrin (644 kg ha⁻¹) was outstandingly successful in controlling a root disease which may have resulted from injury due to nematodes (Table 1).

During the 1950s and 1960s, tests were conducted in the United Kingdom (Benzian 1959, 1965; Aldhous 1972), Australia (Brown 1985), Netherlands (Pouwer and van Doesburg 1967), New Zealand (Thulin et al. 1958; Will and Bassett 1959; Will 1962; Bassett and Will 1964), Canada (van den Driessche 1963a,b; 1969; Agnihotri 1971), Japan (Terashita 1962), Germany (Ruhm 1959) and the United States (Coz 1951; White and Potter 1963). The following synopsis of chloropicrin is paraphrased from van den Driessche (1969).

Chloropicrin is an effective fungicide, has nematocidal properties, and reduces weed growth. Douglas-fir responds well on soils treated with chloropicrin (Will 1962; Thulin et al. 1958; van den Driessche 1963a, 1968). Chloropicrin may be either injected to a depth of 15 cm or chiseled into the soil at a rate of 336 kg ha⁻¹. Chloropicrin applied at 168 kg ha⁻¹ in two coastal nurseries markedly improved growth of Douglas-fir, and 84 kg ha⁻¹ caused some positive response (van den Driessche 1963b).

Both soil temperature and soil moisture influence the effectiveness of chloropicrin. Soil moisture content of 1 to 15% is optimum and, though soil temperatures around 20°C are desirable, satisfactory results were obtained with soil temperatures

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Table 1. Effect of 644 kg ha⁻¹ of chloropicrin on seedling production at the Ashe Nursery in 1947.

Treatment	Total seedlings m ⁻²		Plantable seedlings m ⁻²		"Healthy" plantable seedlings m ⁻²	
	Longleaf	Slash	Longleaf	Slash	Longleaf	Slash
Chloropicrin	106	360	102	300	70	236
Untreated	69	397	62	309	0	109

varying from 2 to 20°C (Benzian 1965). Chloropicrin deteriorates with storage and good results can only be obtained with fresh material.

Aldhous (1972) summarized some early fumigation trials from 14 nurseries in Scotland and England. In February or March, chloropicrin (664 kg ha⁻¹) was injected into the soil at least three weeks before sowing. Sitka spruce (*Picea sitchensis* Bong. Carrière) growing in chloropicrin plots were significantly taller in 69% of the trials. In some 86 trials (which included trials with four other conifers), a significant decrease in seedling production occurred in only 6 trials. Several of the negative responses were from one silt-loam nursery. Aldhous indicated that a three week interval may not be sufficient where fine textured soils remain wet or at nurseries with poor drainage. He suggested that chloropicrin might be hazardous to seedlings if the soil remains wet for a considerable period of time after treatment. Seedling height increased only 50% of the time on fine textured soils. He indicated that on "light to medium loam" soils, the growth gains from fumigation with chloropicrin could shorten the nursery phase by one year.

Recent Nursery Trials

For about two decades (1965–1985) there were few trials with 100% chloropicrin in forest nurseries. Combinations of methyl-bromide and chloropicrin were tested and these mixtures soon became the industry standard. Interest in chloropicrin has recently increased because the production of methyl-bromide in the United States might cease after the year 2001. Trials with 100% chloropicrin have been conducted in Wisconsin (Enebak et al. 1990), Washington (Stevens 1997) as well as in the southern United States (Carey 1994). The following provides some highlights of this research.

Since 1990, the Auburn University Southern Forest Nursery Management Cooperative has conducted fumigation trials in Georgia, Mississippi, South Carolina, Texas, and Virginia. Some studies included chloropicrin at rates from 140 to 392 kg ha⁻¹. Most of the chloropicrin treatments were applied without polyethylene tarps. In no Cooperative study did chloropicrin cause a significant reduction in either size or number of seedlings. Increases in number of seedlings produced occurred in pathogen infested soil in Wisconsin, but thus far, no large increases have occurred in southern nurseries (Table 2). This is possibly due to reduced disease pressure as a result of prior fumigations (Last and Cole 1969).

Effects on Soil Pathogens and Nematodes

Overall, chloropicrin is a better fungicide than methyl bromide. Some believe 1 kg of chloropicrin is as effective as 2 kg of methyl bromide (Table 3). This view is consistent with results from a white pine (*Pinus strobus* L.) study in Wisconsin. Chloropicrin at 196 kg ha⁻¹ was as effective as methyl bromide at 392 kg ha⁻¹ in reducing soilborne *Fusarium*, *Rhizoctonia* and *Pythium* (Enebak et al. 1990). Chloropicrin is also an effective nematicide (Stark 1948; Benzian 1965) and, on an equiv-

alent weight basis, is as effective on nematodes as methyl bromide (Table 3). In one test, chloropicrin at 249 kg ha⁻¹ reduced nematodes by 80% while methyl bromide at 450 kg ha⁻¹ resulted in a 94% reduction (Harris 1991).

Effects on Weeds

Methyl bromide is more effective as a herbicide than chloropicrin. In particular, methyl bromide is better for suppressing yellow nutsedge (*Cyperus esculentus*) and purple nutsedge (*Cyperus rotundus*). In general, it takes two and a half times more chloropicrin to equal the weed control effectiveness of methyl bromide (Table 3). This suggests that 1125 kg ha⁻¹ of chloropicrin might be as effective as 450 kg ha⁻¹ of methyl bromide (the cost of this amount of chloropicrin would approach \$8,800 ha⁻¹). Although chloropicrin has some herbicidal activity (Harris 1991), it will likely not be used for weed control in southern forest tree nurseries. Effective herbicides are currently available for conifers, and if applied appropriately, will be more cost effective than fumigation (McNabb et al. 1995).

Some managers of hardwood nurseries currently use on methyl bromide for both weed control and disease suppression. If these managers decide to fumigate with chloropicrin instead of methyl bromide, they will need to increase their emphasis on weed management. Some may decide to increase the use of herbicides while other managers may choose to employ more handweeding labor (South 1995).

Effects on Hardwoods

Several soil fumigation trials with chloropicrin increased growth of pear (*Pyrus* spp.), apple (*Malus* spp.) and citrus (*Citrus* spp.) (Mai and Abawi 1978; Sewell et al. 1992). In one greenhouse test, chloropicrin (1.66 g 15 kg⁻¹ soil; roughly equivalent to 220 kg ha⁻¹) increased growth of pear and apple seedlings in 14 out of 19 orchard soils (Koch et al. 1980). However, stunting of hardwood seedlings can occur on nurseries with fine textured soils. For example, on a clay soil chloropicrin (581 kg ha⁻¹) reduced height growth of several hardwood species (Pouwer and van Doesburg 1967). In England, chloropicrin at 332 kg ha⁻¹ has been applied in the fall one month before sowing large-seeded hardwoods (Hipps et al. 1997). In the United States, several forest nursery managers have grown hardwoods after treating soil with a combination of chloropicrin and 1,3-dichloropropene. At one nursery in Georgia, seedbeds treated with 80 kg ha⁻¹ of chloropicrin (mixed with 394 kg ha⁻¹ of 1,3-dichloropropene) produced plantable seedlings of sycamore (*Platanus occidentalis*) and sweet gum (*Liquidambar styraciflua* L.) (South 1977).

Effects on Mycorrhizae

The effects of chloropicrin on ectomycorrhiza of white pine (*Pinus strobus* L.) were reported by Enebak and others (1990). There was no evidence that chloropicrin applied under a tarp (196 kg ha⁻¹) adversely affected mycorrhizal colonization. I

Table 2. Effects of chloropicrin fumigation on pine seedling production and size (relative to untreated soil).

Location	State	Year	Rate kg ha ⁻¹	Treatment date	Sowing date	Seedling numbers	Seedling size
Boscobel	WI	1986	196	September 4	October 19	Increase	Increase
Statesboro	GA	1993	280	October 21	May 14	Same	Same
Summerville	SC	1993	280	March 18	April 14	Same	Increase
Olympia	WA	1993	224	July 30	May 3	Decrease	Increase
New Kent	VA	1994	336	April 14	May 3	Same	Increase
Winona	MS	1994	278	April 27	May 18	Same	Same
Glennville	GA	1996	392	February 16	April 10	Same	Increase
Texas	TX	1996	392	March 23	April 16	Same	Increase

fact, on one sampling date (13 August, 1987) seedlings from the chloropicrin treatment had almost twice the mycorrhizal colonization of seedlings growing in nonfumigated soil. Ectomycorrhizal spores are wind-blown and reinfestation of the soil may have occurred after fumigation.

Endomycorrhizal spores are soil-borne and typically are not transported by winds. Therefore a reduction in mycorrhizal colonization might occur more frequently among endomycorrhizal species than in pines. In one greenhouse study, chlamydospores of *Glomus mosseae* were added to soil prior to fumigation (O'Bannon and Nemec 1978). Soil was treated in sealed containers for four days. Eight months after treatment, no viable chlamydospores were found in either chloropicrin (326 kg ha⁻¹) or methyl bromide (487 kg ha⁻¹) treated soil. However, the weight of sour orange seedlings (*Citrus aurantium* L.) grown in chloropicrin treated soil (7.9 g seedling⁻¹) was as large as that from either the methyl bromide (5.9 g seedling⁻¹) or nonfumigated soil (6.5 g seedling⁻¹). In contrast, a reduction in the percentage of mycorrhizal roots of rough lemon (*Citrus jambhiri* L.) resulted in a reduction in leaf area (Weir et al. 1980). Roots growing in chloropicrin treated soil (332 kg ha⁻¹) were 60% infected with mycorrhizae and roots in dazomet treated soil (400 kg ha⁻¹) were 36% infected (roots in nontreated soil were 96% infected). Foliar growth was slightly stunted with chloropicrin (17% reduction in shoot weight) and dazomet caused a 45% reduction.

Sewell et al. (1992) suggested the positive or negative effects of chloropicrin depend on soil phosphorus content. When soil phosphorus was low (< 20 ppm), the reduced incidence of vesicular-arbuscular mycorrhiza negatively affected apple seedling growth. However, after adding phosphorus to the soil, the seedlings exhibited a positive response to chloropicrin fumigation (even when mycorrhizal infection was reduced).

Hardwood seedbeds in the United States are often fumigated with a mixture of methyl bromide and chloropicrin. In one study in North Dakota (Riffle 1980), increasing the percentage of chloropicrin in a mixture with methyl bromide did not reduce endomycorrhizal development (when compared to 98% methyl bromide). Hardwood seedlings growing in soil treated with either (1) 98% methyl bromide at 384 kg ha⁻¹; or (2) 179 kg ha⁻¹ of chloropicrin plus 362 kg ha⁻¹ of methyl bromide; had 80% of their root segments colonized with endomycorrhiza. Seedlings growing in nonfumigated soil had 98% endomycorrhizal root segments.

Effects on *Trichoderma*

Fungi in the genus *Trichoderma* are considered to be beneficial for nursery seedlings (Mattis and Badanov 1973; Kelley 1976; Duda and Sierota 1987; Huang and Kuhlman 1991).

Table 3. Relative amount of chemical required to control soil pests (Adapted from Goring [1962] and Goring and Hamaker [1972]).

Fumigant	Nematodes	Fungi	Weed seed	Insects
Chloropicrin	4	5	12.5	1
Methyl Bromide	4	10	5	1
1,3-dichloropropene	3	30	20	1.5

Some *Trichoderma* species increase the speed of pine seed germination (Dong et al. 1987). One benefit from chloropicrin fumigation is an increase in *Trichoderma* soon after fumigation. This effect has been known for some time. In Ireland, the overall incidence of soil fungi was reduced with chloropicrin (320 kg ha⁻¹) but *Trichoderma* was increased. Roots growing in chloropicrin treated soil had two to six times the *Trichoderma* of those in untreated soil (McIlwaine and Malone 1976). In Belgium, fumigation with chloropicrin (697 kg ha⁻¹) resulted in a five-fold increase in *Trichoderma* at a soil depth of 20 cm (Welvaert 1974).

Assessments on the effect of soil fumigation on *Trichoderma* populations have been made in several studies in southern pine nurseries. In general, fumigation with either chloropicrin, or methyl bromide increases the population of *Trichoderma* soon after fumigation (Table 4). In some trials, fumigation with chloropicrin doubled the population of *Trichoderma*. In contrast, treating with dazomet tended to reduce numbers of *Trichoderma*. Similar findings were reported by Welvaert (1974).

Effects of Using a Polyethylene Tarp

Chloropicrin can be applied with or without a polyethylene tarp. Before 1970, most applicators did not use a plastic tarp although a few did (Brown 1985). The pesticide label suggests a higher rate may be required when no tarp is used. However, only a few trials in forest nurseries have examined the effects of tarping (Carey 1994). Possibly due to a limited amount of disease pressure, there was no appreciable effect of tarping at two southern pine nurseries. However, there was also no need for a tarp when applying chloropicrin to control a bacterial wilt of tomatoes (Enfinger et al. 1979). Since 100% chloropicrin is applied as a liquid, the material remains in the soil longer than nontarped methyl bromide. The additional cost of applying a tarp might be offset somewhat by a reduction in chemical. For example, the cost of fumigation with a tarp might be \$3,600 ha⁻¹ (200 kg ha⁻¹) while no tarp might cost \$3,000 ha⁻¹ (250 kg ha⁻¹). Chloropicrin is often applied without a tarp to soils for strawberries and other crops. For some crops, fumigation with chloropicrin without a tarp has been as effective in reducing root rot as methyl bromide applied under a tarp (Last and Cole 1969).

Table 4. Percentage change (increase or decrease) in *Trichoderma* populations (relative to nontreated soil) for chloropicrin (100%), methyl bromide and chloropicrin (67%+33%) and dazomet.

	State and year					
	GA ¹ -93	SC ² -93	GA-94	MS ³ -94	VA ⁴ -94	GA-96
Chloropicrin	+211%*	-19%*	+278*	+67%*	+64%	+95%*
67% methyl bromide and 33% chloropicrin.	+268%*	+55%*	-	+59%*	-24%	+108%*
Dazomet	-91%	-67%*	-	-17%	83% NR	-
Colonies per plate for untreated soil	(2.0)	(30.5)	(3.4)	(6.4)	(7.5)	(6.1)
Days after treatment	436	64	201	53	60	58

NR = treatment not replicated

¹Georgia.

²South Carolina.

³Mississippi.

⁴Virginia.

* = Statistically different from nontreated soil

Table 5. The increase in plantable seedlings required to equal the cost of soil fumigation.

Seedling value	Fumigation cost ha ⁻¹	Additional seedlings needed ha ⁻¹	m ⁻²	% increase in conifer stand (1.5 million base)	% increase in hardwood stand (0.5 million base)
\$0.03	\$3,600	120,000	(18)	8%	24%
\$0.06	\$3,600	60,000	(9)	4%	12%
\$0.12	\$3,600	30,000	(4.5)	2%	6%
\$0.18	\$3,600	20,000	(3)	1.3%	4%
\$0.36	\$3,600	10,000	(1.5)	0.7%	2%

Economics of Fumigation with Chloropicrin

The motivation for soil fumigation can be looked at from either a financial or pathological perspective (van Assche 1974). From a financial perspective, as crop value increases, the motivation for soil fumigation increases. This helps explain why chloropicrin is used more for the production of strawberries than for either corn or soybeans. Likewise, the final decision regarding fumigation will depend on whether seedlings are valued at either \$0.03 or \$0.18 each. At many nurseries, only the cost of production is considered. However, with some companies, seedlings are assessed a higher value due to a consideration of the net present value of the seedlings with respect to timber production. In other words, genetically improved stock (South 1987) and morphologically improved seedlings (South 1993) have a higher net present value than unimproved seedlings. In some situations, the net present value may be six times higher than the cost of production. Rarely are these values considered when determining the benefit/cost ratio for soil fumigation.

Decision models can be developed to assist growers in determining the economic threshold level for soil fumigation (Bailey and Matyac 1989). An example (Table 5) illustrates how many additional seedlings need to be gained to justify an investment of \$3,600 ha⁻¹ (assuming a hectare of nonfumigated seedbed will produce either 1.5 million conifer seedlings or 0.5 million hardwood seedlings). A gain of only 20,000 plantable seedlings ha⁻¹ is needed when seedlings are valued at \$0.18 each. This would be about a 1.3% increase in seedling production for pine seedbeds or a 4% increase for hardwoods.

Several nurseries have been permanently closed as a result of soil-borne disease (Brown 1985; Juzwik et al. 1988). When virulent soilborne pathogens are present, chemical fumigation can sometimes double seedling production (Sutherland and Adams 1965; Agnihotri 1971; Enebak et al. 1990). With this level of production increase, fumigation is

easily justified. Fumigation with chloropicrin in Wisconsin increased crop value by at least \$30,000/ha (assuming a value of \$0.15 plantable seedling⁻¹). However, recently in southern pine nurseries soilborne diseases have seldom been epidemic and therefore dramatic increases in seedling production of the magnitude illustrated (Table 1) are now rare. Therefore, soil is fumigated about once every four years. At these nurseries, the cost of fumigation is spread over two (sometimes three) seedling crops. The required increase in seedling production (Table 5) need not occur just during the first year after treatment. For example, at \$0.06 per conifer seedling, fumigation could be justified if the crop production was increased by 3% the first year and 1% the second year.

In order to maintain a good reputation, some nursery managers will cite disease prevention as the motive for soil fumigation. The use of chloropicrin might affect the number of disease free seedlings but may not affect the number of plantable seedlings. For example, the number of "plantable" slash pine seedlings was not increased by chloropicrin (Table 1) but the number of "healthy" seedlings was doubled. If both diseased and healthy seedlings are valued the same, then some might say there was no need to fumigate. However, if two nurseries are competing for seedling sales, the nursery that consistently produces disease free seedlings will have an advantage over nurseries that produce plantable diseased seedlings once or twice a decade. The old philosophy of "here are the seedlings, you can either take them or leave them" is no longer valid if healthy seedlings can be purchased from competing nurseries that routinely practice soil fumigation.

In their economic analysis of soil fumigation, some pathologists do not include costs which can occur from reduced out-planting survival. At some nurseries, diseased seedlings that appear healthy will exhibit lower outplanting survival than healthy seedlings (Saunders et al. 1992; Barnard et al. 1985; Barnard

1994). However, in a totally integrated pest management system, nursery managers should strive to avoid producing asymptomatic, diseased seedlings. This goal can be accomplished by either prevention (e.g. judicious use of soil fumigation) or by culling a large number of asymptomatic seedlings. One problem with culling asymptomatic diseased seedlings is that healthy seedlings will also be discarded. To avoid a "threat" of nursery-to-field carryover of a pathogen, some pathologists do not recommend soil fumigation. Some suggest not sowing pathogen infected seedbeds (Sutherland 1984) or skipping beds with disease during lifting. However, the elimination of entire seedbeds is not a desirable choice in years when the demand for seedlings far exceeds the supply.

Conclusions

If production of methyl bromide ceases in the United States, many managers of bare-root nurseries will need to adjust their pest management programs. Those that adopt the practice of fumigating with chloropicrin may experience an easy transition since its suppression of pathogens and nematodes appear to be similar to methyl bromide. Some managers may select chloropicrin as their preferred fumigant due to the residual "biocontrol effect". This fumigant often increases soil populations of *Trichoderma* which can remain elevated for several months after fumigation. However, managers that have been relying on methyl bromide for weed control may need to sharpen their weed management skills. Some managers may choose to increase the use of selective herbicides.

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Economics of Soil Fumigation

Methyl bromide is a natural compound produced in large quantities by oceans and from forest fires. It has been estimated that oceans produce 132 to 352 million pounds per year, and biomass burning produces 22 to 110 million pounds per year. Synthetic methyl bromide is used in the production of strawberries, tomatoes, tobacco, peppers, turf, ornamentals, and bareroot tree seedlings. Growers in the United States fumigate soil with about 36 million pounds of methyl bromide each year; quarantine and structural fumigation account for about 6 million pounds per year.

In 1997, USDA Forest Service nurseries used more than 13,000 pounds of methyl bromide-chloropicrin to produce 52 million seedlings. This equates to about 245 pounds of fumigant per million seedlings. Assuming that 80 percent of southern pine nurseries produce two

seedling crops per fumigation (and therefore fumigate the soil once every three or four years), and that 10 percent fumigate before each seedling crop, then we can estimate that about 450,000 pounds of fumigant were used in forest nurseries in the southern United States. This is about 1 percent of the total amount of methyl bromide used in the nation that year.

Although the cost of using methyl bromide can exceed \$1,400 per acre, most nursery managers in the South can economically justify its use once every three or four years (for instance, with two 1+0 seedling crops followed by one or two years in cover crops). The increase in crop value, plus the savings in seed and pest control, often more than compensate for treatment costs. Even so, some people say the quality and quantity of southern pine seedlings from nonfumigated soil are acceptable. However, data from the Auburn University Southern Forest Nursery Management Cooperative (AUSFNMC) suggest otherwise. This arti-

cle reviews some recent results from both AUSFNMC and Forest Service research with emphasis on economic aspects.

Fumigation Studies

AUSFNMC has conducted a number of soil fumigation studies since 1976. Trials often show a difference between statistical significance and economic significance. Many studies report a numerical increase in "plantable" seedlings, but this increase is sometimes not statistically significant. Because of inherent variations in the nursery bed, statistical significance typically requires a 12 percent or greater increase in plantable seedlings. But it only takes a 4 percent increase in crop value to pay for the cost of fumigation. Therefore, a "real" increase of 4 percent in crop value is often not statistically significant. Most nursery managers who choose to fumigate do so based on economic considerations instead of statistics.

Economic gains in the nursery are affected by seedling quantity, which is de-

FYI

Phytoremediation: Using Plants as Pollution Solutions

A new book, *Phytoremediation: Using Plants as Pollution Solutions*, by D. B. Clark and others, is a comprehensive guide to the use of plants to clean up contaminated sites. The book covers the basics of phytoremediation, including the types of plants that can be used, the mechanisms of plant uptake and transformation of pollutants, and the design and implementation of phytoremediation systems. It also provides a detailed overview of the current state of the field, including the latest research and the challenges ahead. The book is a valuable resource for anyone interested in this emerging technology.

Phytoremediation is the use of plants to clean up contaminated sites. It is a natural and cost-effective method of cleaning up the environment. Plants can absorb and store pollutants in their roots, leaves, and stems. They can also break down pollutants into less toxic substances. Phytoremediation can be used to clean up a wide range of pollutants, including heavy metals, organic chemicals, and nutrients. It is a promising technology that has the potential to revolutionize the way we clean up the environment.

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terminated by the number of plantable seedlings per acre, and seedling quality, which is determined by the number of Grade 1 seedlings (root-collar diameter 4.8 mm or larger) produced per acre. For loblolly and slash pine, an increase of one plantable seedling (root-collar diameter greater than or equal to 3.2 mm) per square foot can represent an increase in crop value of about \$1,015 per acre. Therefore, fumigation costs can be justified by 1.5 more seedlings per square foot. Although some Forest Service researchers considered seedling quality and quantity acceptable in all their nonfumigated plots, a 1997 report from a three-year Forest Service-funded study in Florida shows that fumigation increased crop value by 30 percent, 5 percent, and 8 percent, a gain of 4.7, 1.2, and 1.9 seedlings per square foot for the first, second, and third years of the study. Although most nurseries in the South do not fumigate the soil every year, the Florida study illustrates why some nursery managers choose to fumigate before each crop. The average increase in crop value at some nurseries can justify the cost of annual fumigation, even though the gains for the second and third year were not statistically significant.

In three recent AUSFNMC studies, the difference between nonfumigated crops and those receiving the best fumigation treatment ranged from three to nine plantable seedlings per square foot, which represents an increase in crop value of \$3,045 to \$9,135 per acre. Reductions in hand-weeding costs could be added to this number. When the production of Grade 1 seedlings is considered, the economic gains are even greater.

Today in the South, a number of organizations value large-diameter seedlings more than smaller seedlings. Grade 1 seedlings are worth more than smaller seedlings because they grow quickly after outplanting, and survival is slightly higher because they have more roots and better root-growth potential. On average, a Grade 1 seedling could have a present net worth of \$.10 more than a Grade 2 seedling (a plantable seedling with a root-collar diameter of less than 4.8 mm). Using this type of economics (the same type used to justify genetic improvement), an increase of just one Grade 1 seedling per square foot can increase the net worth of a crop by \$2,900 per acre. For this reason, some nurseries set a goal of producing 80 percent Grade 1 seedlings,

as opposed to 80 percent Grade 2 seedlings. When seedling quality is considered, an increase of one Grade 1 seedling per two square feet could justify the cost of fumigation.

Forest Nursery Impacts

In 1993, the USDA's National Agricultural Pesticide Impact Assessment Program assessed the economic impact of eliminating methyl bromide. The program determined the potential loss to various agricultural crops. The largest estimated economic return per pound of methyl bromide was for forest tree seedlings, at \$109 per pound. That equals about \$30,000 per nursery acre. Is that a realistic estimate? In one AUSFNMC study, nonfumigated soil produced 2.5 Grade 1 seedlings and 11.5 Grade 2 seedlings per square foot. Fumigated plots produced more plantable seedlings and more quality seedlings (14 Grade 1 seedlings plus 5.4 Grade 2 seedlings per square foot). Increasing the present value of Grade 1 seedlings for expected growth makes the value in control plots and in fumigated plots, respectively,

\$21,500 and \$59,300 per acre. This difference is even greater when adding the loss of genetically improved stock. Although not all nurseries realize such a gain from soil fumigation, this example illustrates why some nursery managers choose to fumigate the soil once every three or four years.

Maintaining a good reputation is important for both private and state nurseries. Keeping a good customer base is easier for managers who have a reputation for producing disease-free nursery stock. Nursery managers know it may take years to build a good reputation and just one bad disease year to threaten it. Over a two-year period, an acre of nursery can produce seedlings worth \$50,000 to more than \$170,000. Therefore, spending \$1,500 per acre for soil fumigation every three or four years to help ensure a good crop does not seem so great, especially because researchers do not accurately predict when seedling losses will occur in any particular year.

—David South, professor, and Bill Carey, research fellow, Forestry and Wildlife Sciences, Auburn University

FYI

Greenhouse Gas Bibliography Available

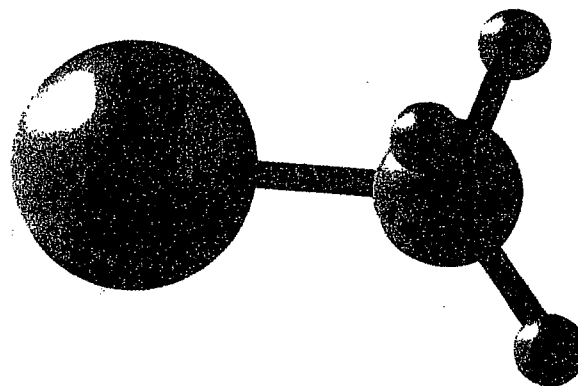
IEA Bioenergy, a division of the International Energy Agency (IEA), has recently released its bibliography, *Greenhouse Gas Balances of Commonly Produced Wood Products and Pulp and Paper*. The bibliography is available as an Adobe Acrobat PDF file from the IEA Bioenergy Website: <http://www.iea-bioenergy.org/publications/gas25/>

This bibliography of the bibliography includes a list of publications, unpublished reports, and databases and documents under 1000 pages in 100 titles. In addition to providing links to documents and other resources, the bibliography lists other data with greenhouse gas data as they relate to different types of forestry, such as agriculture and forestry, and provides information on the greenhouse gas emissions of some selected forest and agro-forestry systems. Information on the bibliography is useful for researchers, with forestry, energy, and other sectors.

The bibliography includes materials by author, subject, and year, and is also searchable by subject, list of authors, and year. The bibliography is available as a PDF file and can be downloaded to a computer. The bibliography is available on a website, as well as information on the IEA Bioenergy Website. The bibliography is available as a PDF file and can be downloaded to a computer. The bibliography is available on a website, as well as information on the IEA Bioenergy Website.

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Methyl Bromide Alternatives



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The Status of Methyl Bromide Alternatives

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This section contains all back issues of the Methyl Bromide Alternatives journal. It is now available online for free at <http://www.ars.usda.gov/alternatives/>. You can also find the Methyl Bromide Alternatives journal at <http://www.ars.usda.gov/alternatives/>.

This journal is a free-of-charge publication for researchers and industry.

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Methyl bromide's reign as the gold standard of soil fumigants became tarnished as its ozone depleting properties surfaced. In 2005, methyl bromide will be lost to growers as a soil treatment option, and other practices and compounds must fill the void. ARS and others have put significant efforts into researching various ways to fill the gap that will be left when methyl bromide is completely unavailable. This report is a compilation, or a status of sorts, of the leading options available to growers in the United States.

Before the methyl bromide mandatory reductions began in 1999, U.S. agriculture used about 60 million pounds of the fumigant. Soil fumigation accounted for 75 percent of the methyl bromide used, with about 11 percent used to fumigate harvested commodities during storage and import or export. Another 6 percent of methyl bromide was used to fumigate structures such as food processing plants, museums, transport vehicles, and warehouses. The last 8 percent was used to produce other chemicals.

While quarantine use is currently exempted from the upcoming ban, the Montreal Protocol Technology and Economic Assessment Panel may reconsider the exemption. In 1998, the latest year for which statistics are available, the United States used approximately 570,015 pounds for quarantine purposes. In exporting U.S. goods to other countries, fumigation with methyl bromide may be required. Methyl bromide is also used at U.S. ports-of-entry to disinfest commodities found, on inspection, to be infested with nonindigenous pests, the introduction of which may irreparably harm U.S. agriculture.

The primary focus for the U.S. Department of Agriculture in facing the loss of methyl bromide is research, although technology transfer and education activities with the private sector are also included. Additional funding has been given to assist in the registration of potential alternative fumigants. The Agricultural Research Service (ARS), which serves as the lead agency in these activities, has established a national

program called Methyl Bromide Alternatives which includes all ARS research on this topic. Information about the program and the research being conducted can be found at the web site:

<http://www.nps.ars.usda.gov>.

ARS Research on Alternatives

Preplant Soil Fumigation

Research on preplant soil fumigation consists of investigations of alternatives that use other chemicals, biological controls, disease/pest resistant plants, modified cultural practices, and integrated pest management practices to control weeds, pathogens, nematodes, and damaging insects. Viable methyl bromide alternatives are difficult to identify compared to replacements for other ozone depleters because many factors affect the efficacy: crop and soil type, climate, and target pests. These factors change from one geographical location to another; therefore, it is important to be aware that technology developed in one location is most successfully used in the areas in which the research was conducted. Two chemicals, iodomethane (methyl iodide) and propargyl bromide, have shown promise in field studies. Iodomethane has an advantage over the chemically similar methyl bromide—it photodegrades before reaching the stratosphere, so it is not an ozone-depleting substance. At

this time, however, neither iodomethane nor propargyl bromide are registered as pesticides and will have to go through the process of registration, which is costly and time-consuming, before they are available to producers. Also, restrictions on use may be implemented due to concerns about its environmental fate since many of the growing regions are close to schools and residences.

Because the bulk of preplant methyl bromide, nearly 80 percent, is used on strawberries, tomatoes, ornamentals, peppers, and nursery crops, ARS' primary research focus has been on these crops with special emphasis on tomatoes in Florida and strawberries in California as model crops. Additional research has addressed replant difficulties often associated with perennial crops such as grapes, apples, and peaches.

ARS' strategy for evaluating potential alternatives is to first test the approaches in controlled experiments to determine efficacy and follow up with field tests of those determined to be effective. The impact of the variables that affect efficacy is addressed by conducting field trials at multiple locations with different crops and against various diseases and pests. Those alternatives that are effective in field trials are further tested in field-scale validations, often by growers in their own fields. Research teams that include ARS and

university scientists, extension personnel, and grower representatives meet periodically to evaluate research results and plan future trials.

Vegetable Crops

In the United States, tomato crop production uses 24 percent of preplant methyl bromide, more than any other crop. Peppers account for 12 percent. Methyl bromide is used for preplant fumigation of soil in both nurseries and fields before transplanting. Target pests include soil-borne pathogens, particularly *Fusarium oxysporum*, *Phythium* spp., and *Phytophthora* spp.; nematodes, especially root knot nematodes (*Meloidogyne* spp.); and weeds such as purslanes, spurge, and nutsedges.

The most promising fumigant alternatives for control of nematodes, pathogens, and weeds are a combination of metam-sodium plus chloropicrin, Telone (1,3-dichloropropene, or 1,3-D) C-17 (83 percent 1,3-D and 17 percent chloropicrin), Telone C-35 (65 percent 1,3-D and 35 percent chloropicrin), propargyl bromide, pebulate (Tillam) plus Telone C-17, and iodomethane (methyl iodide), according to research results in 2000 from Dr. Joseph Noling, an extension nematologist with the University of Florida's Institute of Food and Agricultural Sciences at Lake Alfred, Florida.

According to a 1997 U.S. EPA study, metam-sodium and plastic mulch controlled all weeds tested in the southeastern United States except nutsedge, the most bothersome weed in horticultural crops. Noling reports that metam-sodium displays erratic control, with excellent control in some studies and very little in others. Although this variability is attributed to differences in application, it still presents a major shortcoming. The use of paper mulch, a cultural approach, is also being studied for nutsedge control. Preliminary small-scale tests have demonstrated good nutsedge suppression, and this approach also eliminates the need for polyethylene mulch. Although this research has just been started, it reflects that long-term, more sustainable approaches are being studied in addition to short-term, chemical alternatives.

While biological controls show promise for control of pathogens and weeds in vegetable nurseries and production fields, effective control may require several years of continuous treatment. Another possible biological control is competitive displacement of pathogenic organisms in soil through the use of nonpathogenic organisms and soil amendments. In another approach, Nancy Kokalis-Burrelle at USDA's U.S. Horticultural Research Laboratory at Fort Pierce, Florida, uses plant growth promoting rhizobacteria (PGPR) that have enhanced the

growth of tomato and pepper transplants and increased tomato yields. Incidence of *Fusarium* was decreased in this study in some PGPR plots. Studies conducted by C. Douglas Boyette at USDA's Southern Weed Science Research Unit at Stoneville, Mississippi, indicate that a fungal pathogen, *Myurothecium verrucaria*, shows promise for controlling weeds in pepper and tomato plots without affecting the transplants. Additional biological control agents that are under development include *Dactylaria higginsii*, which, after having been shown to be extremely effective in controlling purple nutsedge in small-scale field trials, is now under evaluation by Erin Roskopf in large-scale plots through a cooperative research project between USDA and the University of Florida. Roskopf, a research microbiologist at USDA's U.S. Horticultural Research Laboratory in Fort Pierce, Florida, is also developing a biological control agent, *Phomopsis amaranthicola*, for use in vegetables and ornamentals. This fungal plant pathogen significantly affects the growth of pigweeds (*Amaranthus* spp.) and has been field-tested in small-scale trials over several seasons.

Cultural controls, another nonchemical approach, show promise and are under continual testing. A period of several years is necessary for this approach to work at an optimal level since pest population levels are reduced each succes-

sive year. Bell and chili peppers that demonstrate high levels of resistance to root-knot nematodes have been developed and commercially released. Crop rotation has reduced nematode populations in pepper fields, resulting in increased yield. Soil solarization, though it works well on occasion, has performed inconsistently. Water quality issues have limited the practice of flooding fields to kill pests in regions that have a high water table, such as some parts of Florida.

Strawberries

Producers of strawberries are the second largest preplant users of methyl bromide in the United States, targeting pests such as soil-borne pathogens, nematodes, and weeds. Soil-borne pathogens of particular note are *Phytophthora*, *Phythium*, *Rhizoctonia*, and *Verticillium dahliae*. Methyl bromide is used for preplant treatment of soil in nurseries and in production fields before transplanting strawberries. In the nursery industry, the use of methyl bromide is critical because healthy, vigorous plants provide growers with a fighting chance to control disease problems in the field.

In the field of nonchemical approaches, several PGPR strains seem to enhance the growth of strawberries and are being further tested in field studies. While resistance to fungal pathogens is under

evaluation, only low levels of resistance have been identified. Soil solarization, in limited field trials in Florida, has shown yields that are comparable to those of methyl bromide treated plots, although unpredictable weather events will limit its usefulness. In California, where most commercial strawberries are grown, soil solarization is not an option due to a lack of solar radiation and low temperatures.

Thomas Trout of ARS' Water Management Research Laboratory in Parlier, California, and Hussein Ajwa (formerly of the Water Management Research Laboratory, now with University of California-Davis) found that various mixtures of 1,3-D/chloropicrin resulted in yields comparable to methyl bromide fumigation. Continuing studies are being conducted to determine minimum effective rates, optimum application conditions, and the impact of virtually impermeable film on efficacy and rate of application. Ajwa and Trout, in conjunction with the California Strawberry Commission, conducted 4 years of field trials in growers' fields to test and demonstrate the most likely effective alternatives to methyl bromide fumigation for preplant soil treatment for strawberries. Nearly all California strawberries are grown with preplant fumigation with methyl bromide/chloropicrin mixtures, which typically doubles marketable yield. Mixtures of 1,3-D and chloropicrin and chloropicrin alone, in Ajwa and Trout's

research plots in 2000, seem to give good response with slightly smaller yields (5 to 15 percent) compared to those with methyl bromide. These chemical alternatives have disadvantages that include greater weed problems; especially with chloropicrin alone; longer waiting times before planting; and regulatory limitations on use. Drip application, according to current studies, may reduce emissions and worker risk. Although fungicides, such as metalazyl (Ridomil) and fosetyl-aluminum (Aliette), slowly reduce a portion of the fungal spectrum encountered in fields over a period of years, the lack of control of other pathogens does not support this approach. It appears that in the near future, alternative chemical fumigants are the only technology likely to replace methyl bromide for control of soil-borne pathogens in strawberry nurseries and production fields.

Grapes, Fruit Trees, and Nut Trees

Methyl bromide has been used for fumigating soil before planting or replanting to kill pathogens and plant parasitic nematodes in the soil. Methyl bromide is capable of destroying most life stages of soil-dwelling organisms as well as the roots of old trees and vines. Without fumigation, roots are likely to remain present for at least 3 years after tree removal. These woody roots provide a food source for a variety of soil-borne nematodes, insects, and

plant pathogens. Viruses, bacteria, and other microorganisms, like fungi, will remain in the soil for as long as the food source is available.

Developing alternatives to methyl bromide for replant of vineyards, as well as fruit and nut trees, is particularly challenging because the results of these studies can only be ascertained over a period of years. Scientists have not been able to isolate pathogens that consistently cause replant disorder. Various species of nematodes are present in the soils, such as ring nematodes in sandy soils and pin nematodes in sandy-loam soils. In some instances of replant disorder, small roots are evident but no obvious pathogens are present.

A number of nonchemical approaches are being explored, including biocontrol and growth enhancement agents. Results of these studies are several years away. A number of cultural control methods appear promising. Some field studies have been set up to determine whether fallowing for several months to several years and the use of cover crops may alleviate replant disorder. The use of some wheat cultivars as a cover crop seems to reduce levels of pathogenic microbes in apple orchards, according to Mark Mazzola, a plant pathologist in ARS' Tree Fruit Research Laboratory in Wenatchee, Washington, and Yu Huan Gu, formerly of the Tree Fruit Research Laboratory, in studies

conducted in 2000. Under certain conditions, preplant soil solarization also appears to be a viable alternative for control of the ring nematode (*Criconeella xenoplax*) in orchards. Alterations in cultural practices, such as soil excavation in the fall prior to planting and subsequent exposure of this soil to freeze/thaw cycling during the winter, or establishing new plants in the old aisle rather than the old row, appear effective in reducing replant problems.

Another viable alternative to methyl bromide for some trees seems to be host-plant resistance; for example, "Deep Purple" rootstock for fruit and nut trees appears resistant to pathogens in orchards. However, graft compatibility determinations require waiting for symptoms to appear, which can take years. "Guardian" rootstock demonstrates exceptional resistance to peach tree short life induced, in part, by the ring nematode and may prove to be a viable alternative to preplant methyl bromide fumigation for nematode control.

At ARS' Water Management Research Laboratory in Parlier, California, Cynthia Eayre is investigating chemical controls. Preliminary results from 2 years of data, reported in 2000, show that iodomethane effectively controls peach replant disorder. Combinations of resistant rootstock and either 1,3-D or metam-sodium also appear to be possible alternatives for methyl bromide for control of peach

replant disorder. Fungicides to control soil-borne pathogens have been used unsuccessfully.

Sally Schneider, also of ARS' Water Management Research Laboratory, treated a 65-year-old vineyard that was infested with significant plant parasitic nematode populations with drip-applied Telone II EC and shank-applied iodomethane. The field was then replanted with three grape rootstocks that demonstrated broad resistance to most nematodes in grape production areas. Three years after planting, the Harmony rootstock supports minimal populations of the root knot nematode, even in untreated plots, but supports higher populations of the citrus nematodes than either Thompson Seedless or Teleki 5C. Iodomethane and Telone/Vapam combinations appeared to act as adequate replacements during the 3-year evaluation.

Postharvest Research

Developing alternatives for controlling pests of stored and exported commodities is the realm of postharvest research. Many commodities cannot be exported legally without methyl bromide treatment to eradicate quarantine pests and certify the commodities pest free. Alternative fumigants, heat and cold treatments, modified atmospheres, and combinations of treatments are various research approaches being explored.

Dried Fruits and Nuts

Low-temperature (10 °C) storage and controlled-atmosphere (5 percent O₂) storage were found to effectively control pests of dried fruits and nuts.

Fresh Fruits

In a number of crops, including citrus and papaya exported from Hawaii and other places and limes imported into Florida, the use of forced hot air for quarantine treatment of fresh fruits has been commercialized. Hot water immersion for quarantine treatment has been commercialized for litchi exported from Hawaii and guavas exported from Florida. Conversely, cold treatments are used commercially for avocado and starfruit exported from Hawaii. Large-scale tests have shown irradiation to be effective for disinfection of sweetpotato weevils in sweetpotatoes exported from Florida, Malaysian and other fruit flies in fruits exported from Hawaii, and maggots in blueberries exported from Florida. Field-study results are used to establish and maintain pest-free zones in lieu of postharvest treatments for fruit flies in citrus exported from Texas. Approximately two-thirds of the fruit, in most years, can be harvested under the requirements of a pest-free zone so that methyl bromide treatment is not required.

Processing Facilities and Warehouses

Methyl bromide is used by many food companies to fumigate processing facilities and storage areas to rid these areas of insect pests. A proven alternative treatment is raising the temperature of the facilities to near 50 °C for 2 to 3 days. Also, a combination of heat and diatomaceous earth seems particularly effective in areas that may be difficult to heat.

Emissions Reductions

A methyl bromide recapture and recycling system was designed by ARS and commercialized, and is now in operation at the Dallas-Fort Worth International Airport. The pilot recapture system vastly reduced the amount of methyl bromide released to the atmosphere—93 to 96 percent of recoverable methyl bromide is captured by the carbon in field tests.

Conclusions

Currently registered alternative fumigants such as metam-sodium, chloropicrin, and 1,3-D seem likely to be the most reliable replacements. However, it is probable that the replacements will not be as reliable as methyl bromide in all cases. These alternatives were once the standard chemicals used but in many cases were replaced by methyl bromide.

For preplant purposes, biological control and host-plant resistance may demonstrate

effectiveness in some cases in the future. Much of the research on these approaches is still to be conducted, and it is unlikely that economic use of these alternatives will be available for many uses before the 2005 phase-out has occurred. Due to the multiple combinations of crop, pest or pathogen, environmental conditions, weed species, soil type, etc., combinations of approaches will be necessary to effectively manage diseases and pests.

For postharvest and export uses, several nonchemical approaches, such as heat/cold treatments and modified atmospheres, demonstrate some possibilities as methyl bromide alternatives. A methyl bromide recapture system has been developed and is in use at one airport in Texas.

Research is only one cog in the machinery to bring reliable, effective, and economical methyl bromide alternatives to farmers and other users of methyl bromide. A critical role must be filled by the chemical industry: registering and marketing any promising unregistered alternatives. It is currently uncertain if there is adequate financial incentive for the chemical industry to bring new products to market in light of the minor-use nature of methyl bromide. Users of methyl bromide will ultimately make decisions, based on several factors including economic considerations, as to whether to

utilize any alternative technologies that become available.

Plantpro 45 as a Control of Soil-Borne Pathogens, Weeds, Nematodes, and Seed-Borne Pathogens

Plantpro 45, a low-risk iodine-based compound, was studied by Nancy Kokalis-Burelle to ascertain its usefulness for soil-borne pathogen and weed control. The results are somewhat mixed. Two years of greenhouse and field trials have shown that Plantpro 45 has some potential for control of root-knot and sting nematodes, some soil-borne fungal and bacterial pathogens, seed-borne fungal pathogens, and economically important weed species.

"Plantpro 45 works by disrupting membranes in organisms. When compounds are in contact with nematodes and eggs in the lab you get good toxicity, but in the soil the effect is lessened," says Burelle. "Soil is a very complex medium and water doesn't move through the soil as expected, and results vary from trial to trial."

Nematode Control

Plantpro 45 showed some reduction of root-knot nematode damage on tomato at multiple field locations in Florida. However, Burelle found it didn't perform as well as methyl bromide.

Methyl bromide alternatives in a bell pepper–squash rotation

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Abstract

Field studies were conducted to evaluate potential methyl bromide alternatives against multiple pests in a bell pepper (*Capsicum annuum* L.) – squash (*Cucurbita pepo* L.) cropping sequence. Early in the growing season, the most effective treatments in suppressing purple nutsedge (*Cyperus rotundus* L.) emergence through the polyethylene mulch were methyl bromide, methyl iodide, and chisel-injected 1,3-dichloropropene plus chloropicrin [1,3-D + C35 (chisel)]. However by the end of the season in 1999, only methyl bromide treatment had less purple nutsedge emerging through the polyethylene than the nontreated control. Each soil-applied treatment resulted in nematode-susceptible pepper plants with lower root-gall indices [*Meloidogyne* spp. (root knot nematode)] than the nontreated control, while there were no differences among treatments with the nematode-resistant pepper cultivar. Total fungi isolated from soil was lower in all treated plots relative to the nontreated control, with the exception of methyl iodide. However, methyl bromide was the only treatment that was consistently effective against *Pythium* spp. and *Fusarium* spp. A treatment of metham prior to planting squash was beneficial in reducing root-gall indices in plots treated with 1,3-D + C35 (chisel) and methyl bromide prior to the pepper crop. Methyl bromide, methyl iodide, and 1,3-D + C35 (chisel) applied before pepper resulted in squash with lower root-gall indices than the nontreated control. Glyphosate applied between the first and second crop eliminated exposed weed foliage through the polyethylene mulch, possibly muting the effects of the second crop treatment on weed densities. Results of this study indicate that there are some potential methyl bromide alternatives available to growers for use in pest control, however there does not appear to be one broad-spectrum pesticide that will replace methyl bromide. Also, an effective control for nutsedge species within the pepper–squash cropping system is still elusive. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: *Cyperus rotundus*; *Fusarium* spp; *Meloidogyne incognita*; Methyl bromide; *Pythium* spp; Metham; Methyl iodide; 1,3-dichloropropene

1. Introduction

Methyl bromide is an effective soil fumigant used extensively prior to planting many vegetable and fruit crops to control a broad-spectrum of pests that include nematodes, soilborne plant pathogenic fungi, soilborne insects, and weeds. Methyl bromide has been used since the 1950s to eliminate pest problems in many minor-use crops. Many of these crops have a limited number of pesticide alternatives due to the high cost associated with the registration of a pesticide. This high cost coupled with the relatively low numbers of hectares of these crops

makes most pesticide manufacturers reluctant to register pesticides for minor-use crops. While this has been an important issue surrounding minor-use crops, it has been tempered by the availability of methyl bromide and its biocide activities. However, methyl bromide was listed as a Class I ozone depleting substance by the US Environmental Protection Agency in 1993 and its use is scheduled to be halted by the year 2005. While methyl bromide is used for post-harvest pest control of stored products and for pest control of buildings and other structures, it is estimated that 85% of methyl bromide is used in agriculture as a preplant soil fumigant for high value vegetable and agronomic crops (Julian et al., 1998). With the impending elimination of this valuable compound, growers will need viable alternatives to manage a wide range of pests.

Previous research has identified several potential pest management alternatives for methyl bromide in various

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Table 1
Main and subplot treatments applied to pepper and squash crops

	Application method	Rate	Date applied
<i>Main plot (first crop treatments)^a</i>			
Fenamiphos + metham	Broadcast to soil surface ^b + chemigated through drip tape ^c	6.7 kg ai/ha + 240 kg ai/ha	30 March 1998; 31 March 1999
Methyl bromide	Fumigated	440 kg ai/ha	13 April 1998; 30 March 1999
Methyl iodide	Chemigated through drip tape ^c	440 kg ai/ha	13 April 1998; 1 April 1999
1,3-dichloropropene (1,3-D)	Chemigated through drip tape ^c	136 kg ai/ha	13 April 1998
1,3-dichloropropene + chloropicrin [1,3-D + C35 (chisel)]	Chisel injected	146 kg ai/ha + 83 kg ai/ha	13 April 1998; 30 March 1999
1,3-dichloropropene + chloropicrin [1,3-D + C35 (drip)]	Chemigated through drip tape ^c	146 kg ai/ha + 83 kg ai/ha	13 April 1998; 31 March 1999
Nontreated control	—	—	—
<i>Sub-plot (second crop treatments)^d</i>			
Metham	Chemigated through drip tape ^c	240 kg ai/ha	21 July 1998; 26 July 1999
Nontreated control	—	—	—

^aMain plots were 3.6 m × 7.6 m and treatments applied prior to pepper crop.

^bGranular fenamiphos was applied to the soil surface and shallowly incorporated.

^cPlots were chemigated for 60 min using a pump that delivered 126 ml/min. Water was added to each treatment to a total volume of 7500 ml. Following each 60 min treatment application, the lines were flushed with water for 30 min into the treated plots prior to application of the next treatment. This system was equipped with pressure regulators that maintained a consistent 83 kPa through the irrigation tubing.

^dSub-plots were 1.8 m × 7.6 m, each main plot treatment was divided to receive subplot treatments that were applied prior to squash crop.

section), and nematode-resistant and nematode-susceptible bell pepper cultivar were the sub-subplots (Table 1). Main plots were 3.6 m wide and 7.6 m long and consisted of two subplots each 1.8 m wide and 7.6 m long. The subplots were planted to two rows of bell pepper, one of each cultivar, which constituted the sub-subplot.

To allow for aeration prior to crop transplanting, two rows of holes 8 cm in diameter and spaced 30 cm apart were cut into the polyethylene mulch of each bed at 10 and 14 days after the methyl bromide treatment in 1998 and 1999, respectively. Five days after holes were cut in the polyethylene, a single greenhouse-grown pepper plant was planted in each hole with one row of *M. incognita*-resistant 'Charleston Belle' and one row of *M. incognita*-susceptible 'Camelot' pepper per bed on 27 April 1998 and 16 April 1999.

All pepper plots were sprayed on a 7–10-day schedule with 2 kg ai/ha maneb (Manex, Griffin LLC, Valdosta, GA 31601) and 1.3 kg ai/ha copper hydroxide (Kocide, Griffin LLC, Valdosta, GA 31601) in a water volume of 187 l/ha for foliar disease control. All plots received liquid fertilizer injected through the drip irrigation system once a week for a total of 130 kg/ha of nitrogen, 48 kg/ha of P₂O₅, 27 kg/ha K₂O, and 1 kg/ha boron.

Twenty soil cores (2.5 cm-diameter, 25 cm-depth) for nematode assay were collected from each row of pepper at monthly intervals from March through July in 1998 and April through July in 1999. The samples from each row within a plot were pooled and a 150 cm³ subsample was processed by centrifugal flotation method to separ-

ate nematodes from the soil (Jenkins, 1964). A 100 cm³ subsample was assayed for populations of *Pythium* spp. (P₅ARP media) (Jeffers and Martin, 1986), *Fusarium solani* (Mart.) Sacc. and *Fusarium oxysporum* Schlecht-enol:Fr. (modified PCNB) (Papavizas, 1967), *Aspergillus* spp., *Trichoderma* spp., *Penicillium* spp., and *Paecilomyces* spp. (OAES media) (Williams and Schmitthenner, 1960). Roots of five pepper plants from each plot were dug, washed in tap water, blotted dry with paper towels, and rated for root galls caused by *M. incognita* after final harvest. A scale ranging from 1 to 5 was used where 1 = 0%, 2 = 1% to 25%, 3 = 26% to 50%, 4 = 51% to 75%, 5 = 76% to 100% of the root system with galls.

The total number of living plants per plot was recorded in May of each year. Some plants began to show symptoms of wilting even in the presence of adequate soil moisture 4–6 weeks after planting in 1998. The number of wilted and healthy plants was recorded on 10 June 1998 and 10 July 1998.

All fruit were hand-harvested, separated into marketable and cull, counted, and weighed in late June and early July. After the final harvest, all weeds growing in the hole in the polyethylene where the bell peppers or squash plants were planted and those penetrating through the polyethylene mulch were identified and counted. Due to the diversity of weeds that emerged through the crop holes, weeds were divided into two categories: purple nutsedge and other weeds. The other weeds included bermudagrass [*Cynodon dactylon* (L.) Pers.], cutleaf

Table 2

The effect of soil treatment and crop cultivar on pest populations in pepper in 1998^a

Treatment	Root-gall index ^b		Weed densities		
	'Camelot'	'Charleston Belle'	Through polyethylene	Through crop hole	
			Purple nutsedge ^c	Purple nutsedge	Other weeds ^d
			no. per plot		
1,3-D (drip)	1.13 b	1.06 a	23 ab	5 ab	40 a
1,3-D + C35 (chisel)	1.13 b	1.00 a	2 b	1 ab	3 c
1,3-D + C35 (drip)	1.19 b	1.19 a	40 ab	8 ab	36 a
Methyl bromide	1.31 b	1.13 a	0 b	0 b	3 c
Methyl iodide	1.50 b	1.19 a	12 ab	1 ab	16 b
Nontreated control	2.31 a	1.06 a	64 a	10 a	45 a

^aTreatment means were separated using Duncan's multiple range test ($P = 0.05$). Differences among treatments with the same letter within a column could not be detected.

^b*Meloidogyne incognita* (southern root knot nematode) root-gall index was rated on a scale of 1–5 (1 = 0%, 2 = 1% to 25%, 3 = 26% to 50%, 4 = 51% to 75%, 5 = 76% to 100% roots galled at the conclusion of the season).

^cPurple nutsedge (*Cyperus rotundus* L.).

^dOther weeds included bermudagrass [*Cynodon dactylon* (L.) Pers.], cutleaf evening primrose (*Oenothera laciniata* Hill), Florida beggarweed [*Desmodium tortuosum* (Sw.) DC.], goosegrass [*Eleusine indica* (L.) Gaertn.], pink purslane (*Portulaca pilosa* L.), redroot pigweed (*Amaranthus retroflexus* L.), smallflower morningglory [*Jaquemontia tamnifolia* (L.) Griseb.], and Texas panicum (*Panicum texanum* Buckl.).

Table 3

The effect of soil applied treatments on nematode populations and incidence of root galling in pepper in 1999^a

	<i>Meloidogyne incognita</i> ^b		<i>Paratrichodorus minor</i>		<i>Helicotylenchus dihystera</i>		Root-gall index ^c	
Treatment	'Camelot'	'Charleston Belle'	'Camelot'	'Charleston Belle'	'Camelot'	'Charleston Belle'	'Camelot'	'Charleston Belle'
	no. per 150 cm ³ of soil							
1,3-D + C35 (chisel)	9 b	4 b	74 ab	45 ab	0 b	0 b	1.0 c	1.0
1,3-D + C35 (drip)	108 b	15 b	40 b-d	51 ab	0 b	3 b	1.3 b	1.0
Fenamiphos	219 b	4 b	53 bc	71 a	4 b	9 ab	1.3 b	1.0
+ metham								
Methyl bromide	5 b	54 ab	100 a	49 ab	0 b	3 b	1.0 c	1.0
Methyl iodide	4 b	3 b	33 cd	34 ab	0 b	0 b	1.0 c	1.0
Nontreated control	960 a	109 a	10 d	29 b	38 a	23 a	1.7 a	1.0

^aTreatment means were separated using Duncan's multiple range test ($P = 0.05$). Differences among treatments with the same letter within a column could not be detected.

^b*Meloidogyne incognita* (southern root knot nematode), *Paratrichodorus minor* (stubby-root nematode), *Helicotylenchus dihystera* (spiral nematode).

^c*Meloidogyne incognita* root-gall index was rated on a scale of 1–5 (1 = 0%, 2 = 1% to 25%, 3 = 26% to 50%, 4 = 51% to 75%, 5 = 76% to 100% roots galled at the conclusion of the season).

purple nutsedge emergence through the polyethylene mulch in the early season of 1999 (Fig. 1). However, methyl iodide and 1,3-D + C35 (chisel) only suppressed purple nutsedge emergence and growth early in the season; by the conclusion of the season in 1999, only methyl bromide had lower purple nutsedge shoot densities than the nontreated control. These results indicate that in terms of nutsedge control, an effective replacement for methyl bromide has not yet been identified. However, some of these treatments may be a component of a future nutsedge management system.

Weeds also emerged through the holes in the polyethylene cut for the crop transplants. Compared to the nontreated control, only methyl bromide reduced the number of purple nutsedge that emerged through the crop holes (Table 2). Other weeds were suppressed, relative to the nontreated control, by methyl bromide, methyl iodide and 1,3-D + C35 (chisel) in 1998 (Table 2) and by all treatments in 1999 (data not shown). The number of weeds emerging through the crop holes in the polyethylene was 55 and 20 plants in the nontreated plots in 1998 and 1999, respectively. However, the total area of

Table 5
The effect of soil applied treatments on fungal populations in pepper^a

Treatment	<i>Pythium</i> spp.	<i>Fusarium solani</i>	Total <i>Fusarium</i> spp.	<i>Trichoderma</i> spp. (× 1000)	<i>Penicillium</i> spp. + <i>Paecilomyces</i> spp. (× 1000)	Total fungi (× 1000)
	CFU ^b					
1,3-D + C35 (chisel)	29 cd	420 b	760 bc	75.1 a	0 d	93.5 c
1,3-D + C35 (drip)	109 ab	370 b	880 b	77.5 a	0 d	111.4 b
Fenamiphos + metham	63 bc	1750 b	2450 a	5.3 b	8.2 bc	66.4 c
Methyl bromide	1 d	20 c	120 c	1.5 b	4.4 c	36.3 d
Methyl iodide	257 a	8610 a	9970 a	22.3 a	25.7 ab	213.7 a
Nontreated control	237 ab	970 ab	2400 a	24.2 a	76.7 a	304.9 a

^aTreatment means were separated using Duncan's multiple range test ($P = 0.05$). Differences among treatments with the same letter within a column could not be detected.

^bNumber of colony forming units (CFU) per gram of oven-dry soil.

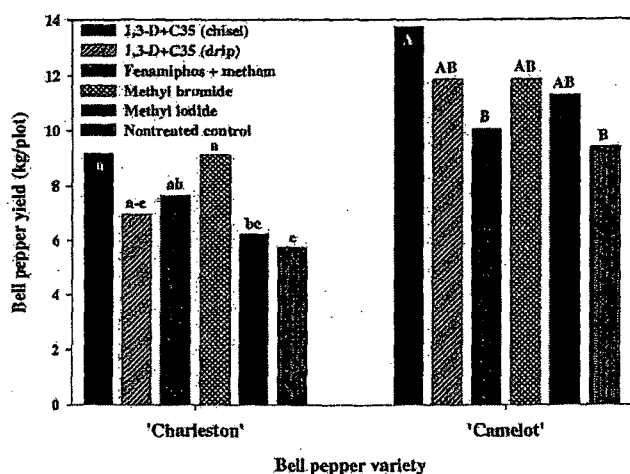


Fig. 2. The effect of soil treatment on pepper yield for both *Meloidogyne incognita*-resistant and *M. incognita*-susceptible pepper varieties in 1999. Treatment means were separated using Fisher's Protected LSD at an alpha level of 0.05; lower case letters were used to differentiate treatments in *M. incognita*-resistant pepper, while capital letters were used to separate treatment means in *M. incognita*-susceptible pepper.

3.2. Squash

Relative to all other treatments, a higher population of *M. incognita* was detected following the first crop treatment of 1,3-D + C35 (chisel) in 'Camelot' pepper that were left nontreated prior to the squash crop in 1998 (Table 6). Differences in *M. incognita* populations could not be detected among all other treatments and the nontreated control for the first crop followed by nontreated control for the second crop in 1998. There were significant differences in number of *M. incognita* recovered from soil among first crop soil treatments in

1999 (Table 7). Treatments of methyl bromide, 1,3-D + C35 (chisel), and fenamiphos + metham applied prior to the first crop resulted in lower *M. incognita* populations than in the nontreated control. There was a significant second crop treatment by pepper cultivar interaction in 1999, which indicated that a treatment of metham applied through the irrigation tubing following the susceptible cultivar of pepper ('Camelot') had lower *M. incognita* soil populations than did the same cultivar that did not have any application for the control of nematodes prior to the second crop. In plots that had resistant pepper cultivar as the first crop, there were no differences in *M. incognita* soil populations between second crop treatments of metham and nontreated plots (Table 7). Previous research indicated that cucumber following nematode-resistant tomato had lower soil populations of *M. incognita* than those following nematode-susceptible tomato (Hanna et al., 1994). Clearly pest resistant cultivars, where possible, should be one component of a methyl bromide alternative system.

Root-gall indices of squash in 1998 indicated no differences among first crop or second crop treatments when squash was planted following the nematode-resistant pepper cultivar ('Charleston Belle') (Table 6). However, there were differences among treatments following the nematode-susceptible cultivar ('Camelot') in 1998. Squash in plots that were treated with methyl bromide (first crop) followed by a nontreated control (second crop) or 1,3-D + C35 (chisel) (first crop) followed by nontreated control (second crop) both had higher root-gall indices than the nontreated control for the first crop followed by nontreated control for the second crop treatment. However, when an application of metham was applied through the drip irrigation tubing prior to the

plots (Table 7). All other treatments were not different from the nontreated control. Differences in plant vigor could not be detected among second crop treatments nor related to the cultivar of the previous pepper crop. Higher plant vigor ratings from the methyl bromide treatment resulted in higher squash yields relative to all other treatments in 1999 (Table 7). The nontreated control was similar in yield to all other nonmethyl bromide treatments. Differences in crop yield in 1998 among treatments could not be detected (data not shown). Approximately 74% of the harvested fruit were marketable from the methyl bromide and methyl iodide plots in 1999, but this was not different from the nontreated control (Table 7). These values were higher than those from plots treated with 1,3-D + C35 (drip) and fenamiphos + metham. Second crop treatments did not have any detectable effect on plant vigor rating, fruit weight, or the percent of marketable fruit (Table 7).

Nutsedges were identified as the most troublesome weeds of vegetable crops in Georgia (Webster and MacDonald, unpublished). While purple nutsedge was a problem during the first crop, the presence of this weed species was erratic in the second crop. Differences in purple nutsedge densities among treatments could not be detected in the second crop in 1998 or 1999, nor could any trends within the data be observed (data not shown). Treatment of the plots between the first and second crop with glyphosate probably had a significant influence on the reduction of purple nutsedge shoots in the second crop. With the exception of the methyl bromide treatments, all plots had purple nutsedge shoot densities greater than 5/m² emerged through the polyethylene and measured 25–61 cm in height at the time of glyphosate treatment. This application of glyphosate reduced the purple nutsedge shoot population in the second crop 82–99%, regardless of the second crop treatment. The nonselective herbicide paraquat is often used to eliminate weedy vegetation between vegetable crops, primarily because of its low price, quick action, and broad spectrum of weed control. However, this will often only provide contact burn of exposed purple nutsedge foliage and will not control any underground tubers. Glyphosate was reported to control nutsedge tubers that were attached to treated foliage (Doll and Piedrahita, 1982). These researchers found that new shoots of purple nutsedge that emerged following glyphosate applications originated from dormant tubers. Based on the reduced nutsedge populations observed in the current study, an application of glyphosate between crops is recommended to assist in weed control in a plasticulture system. However, results of this study indicate that an effective replacement for methyl bromide for weed control within the crop has not yet been found.

Many pests were controlled effectively with methyl bromide (nematodes, soil-borne plant pathogenic fungi, soil-borne insects, and weeds), however, the potential

methyl bromide-replacements investigated in this study do not have the broad-spectrum pest control of methyl bromide. Following the elimination of methyl bromide, pest management in vegetable crops will need to further rely on the principles of integrated pest management (IPM). Correct identification of pests and implementation of appropriate control measures have become increasingly important in the effective management of pests in systems that previously relied on methyl bromide. Instead of a limited number of pest control tactics, new pest management systems will need to rely on multiple components aimed at controlling weeds, nematodes, and soilborne plant pathogenic fungi and insects. These systems in the future may also include a broader arsenal of herbicides for several crops with minor hectareage due to the efforts of the US Interregional Research Project 4 (IR-4) (<http://pestdata.ncsu.edu/ir-4/>), which is a collaborative effort between the State Agricultural Experiment Stations and the USDA-Agricultural Research Service. In addition, integration of cultural practices such as crop rotation (McSorley, 1996), pest resistant cultivars (Thies and Fery, 1997), stale seed bed techniques (Johnson and Mullinix, 1998), precision fertilization and watering, the use of organic amendments (Blok et al., 2000; Gardiner et al., 1999; Kirkengaard and Sarwar, 1999) and the choice of polyethylene mulch (Chase et al., 1998; Patterson, 1998) may also improve pest control and should be investigated across multiple disciplines in future studies.

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